Final Report

TMA Integrated Metrics Assessment Model

FAA Award Number: 04-G-044

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October 18, 2006

SUMMARY

"TMA Integrated Metrics Assessment Model"

TMA is a terminal arrival tool that generally imparts delays to arriving en route aircraft in order to preclude the occurrence of a "rush" i.e., an event where arrival demand exceeds capacity. The independent performance assessment of TMA is valuable and beneficial, however, for a complete characterization of TMA's benefits, its inter-dependent or cross dependent performance metrics must be considered.

An integrated approach for metrics analysis can account for trade-offs that may occur due to a tool impacting metrics across traffic flow management domains i.e., surface, terminal and en route. For example, integrated metrics would consider not only the beneficial impact TMA has on delay, but also its impact on the performance of other tools such as URET.

The objectives of the project are, however, limited to conduct a baseline characterization of pre-TMA metrics for the Philadelphia TRACON (PHL) arrival area, and to perform an analysis of TMA benefits for Houston TRACON arrivals.

The first task is centered on the base-lining the pre-TMA traffic flow characteristic of the Philadelphia TRACON(IAH) arrival area in order to support the operational field evaluation of TMA-MC. The baseline characterization will be used to assist in the evaluation of a TMA Integrated Metrics Assessment Mode. The second task is in the subject of TMA performance evaluation using IAH arrival data provided by FAA.

This report summarizes the works performed under the task of FAA integrated metric analysis in two areas. One is on the baseline status of PHL TRACON, including delay rate and delay time, and flight time interval between meter fixes. One distinctive feature of the analysis presented in the report is that the analysis was performed separately for aircrafts arriving from departure airports located out side of 200nmi radius and those from inside 200 nmi radius. This new approach revealed very interesting statistics and observations that have not been reported or presented before. The other is on the TMA performance on the pre- and post-TMA arrival at IAH in terms of overall arrival delays and en-rout domain time/distance comparison.

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I. Introduction

The current growing air traffic demand in the US airspace system causes congestion and costly delays. Most air traffic demand often exceeds available capacity at some busiest airport which leads to severe congestion during peak arrival periods. A total of 23 airports reported more than 20,000 hr of annual flight delays each in 1991. This is estimated as an average annual loss of $740 million for an average airline cost of $1,600 per hour delay [1]. The aviation industry unarguably agreed that the growing traffic demand in the United States needed to be resolved via proper management and improvement of traffic flow. These concerns lead to the establishment of the Free Flight Phase 1 (FFP1) by the FAA in 1998 [2]. The Free Flight concept permits pilot to use onboard tools to maintain safe distance between planes and reduce reliance on ground controllers without violating safety procedures. The Traffic Management Advisor (TMA) is one out of the five basic automation supportive decision tools introduced by FFP1 program [3].

NASA and the Federal Aviation Administration (FAA) have designed and developed an automation tool known as the Traffic Management Advisor (TMA). The TMA is a time-based strategic planning tool that provides Traffic Management Coordinators (TMCs) and En Route Air Traffic Controllers the ability to efficiently optimize the capacity of demand-impacted airports [4]. TMA is a computer system which runs a highly complex software that assists TMCs in sequencing and scheduling arrivals. It uses flight plan information, wind predictions, and aircraft performance data in performing computations in order to predict and schedule the time an aircraft will reach its destination. Since there are other flights in the air, which must be kept a safe distance apart from each other, TMA advices TMCs when each aircraft should land and in which order to maintain a safe distance. The benefits of TMA are, among others, increased throughput with reduced arrival delays, reduced holding and flight times, and increased departure rates. TMA assists controllers to achieve uniformity of arrival flows which can also lead to an increase in departure rates and a decrease in departure delays.

Major airports on a daily basis experience periods of rushes when arrivals and departures exceeds airport capacity. During these periods of rushes (otherwise known as rush periods or peak periods), TMA is assumed to function efficiently by helping to sequence flights, allocate time slots, reduce delays at congested airports as much as possible, and help TMCs and air traffic controllers to generate and implement an efficient arrival and departure plans for capacity-constrained airports such as Atlanta (ATL), Chicago (ORD), Dallas-Ft. Worth (DFW), Philadelphia (PHL), and Houston (IAH). Therefore, the FAA would need the evaluation of TMA to assure themselves that it is operational especially during the peak periods by comparing statistics of pre and post-TMA rush periods. And if TMA is operational during periods of rushes then the FAA would have helped airlines and passengers in saving time due to reduced delays and money by conserving fuel. But most importantly, the FAA would need and want the evaluation of TMA to help them reduce and manage congestion in the NAS.

Previous report from air traffic controllers indicated that TMA was able to improve arrival throughput and situational awareness [5, 6, 7]. A Metrics Team was established to interface with stakeholders and determine appropriate performance measures and evaluation methodologies to assess FFP1 automation tools. This evaluation plan reflects a collaborative effort between the

FAA and the aviation industry and the process of establishing these metrics clarifies the benefits sought by the airline industry. The FFP1 Metrics Plan is expected to provide better information which would lead to better and cost effective decision making, such as future site deployment of the TMA.

A. Air Traffic Control Management

1. Introduction

The Center-TRACON Automation System (CTAS) comprises of key automated support tools, such as the Descent Advisor (DA), Final Approach Spacing Tool (FAST) and Traffic Management Advisor (TMA). Together these tools provide clearance advisories and decision-making assistance to terminal and center controllers [8, 9, 10]. The main objective of these tools is to provide efficient management and control of arrival traffic within an extended terminal area. Each tool is designed to provide a level of automation, and capability. The DA is primarily designed to assist center controllers in the en route domain by providing accurate, optimum-fuel, and conflict free clearance advisories to compliment TMA's generated schedules. Also, the DA assists the controller in delivering aircraft to the meter fix at a specified time and with specified crossing restrictions in a way that is consistent with aircraft operator preferences. The FAST provides runway assignments and landing sequence that Terminal Radar Approach Control (TRACON) controllers use to efficiently manage arrival traffic in demand impacted terminal airspace. Earlier performance evaluation of FAST at Dallas/Forth Worth airport generated a 13% increase in airport throughput without increase of controller workload. Different studies generated increases in Airport Arrival Rate (AAR) and actual arrival rates of flights when FAST was employed. FAST executes runway assignment in such a way as to minimize overall flight delay, with consideration given to aircraft type, speed, and trajectory. Runway advisories are usually displayed to controllers via radar display.

Meanwhile, TMA capabilities, among others, include limited center controller advisories for metering, time-based metering, arrival traffic flow visualization, and traffic awareness improvement. The Traffic Management Coordinators (TMCs) are the main users of the TMA and their major responsibility is to ensure that demands in excess of airport capacity are efficiently and safely accommodated throughout the airspace. A typical merge point is the meter fix, which represents a position along the meter arc through which the primary flow of traffic enters from en route to terminal airspace.

Next, we discuss about the six flight phases followed by the necessity of TMA and its operational benefits to the aviation industry. Then, we present TMA deployment schedule to selected ARTCC sites.

2. Gate-to-Gate Phases of Flight

In this section, we will describe the various phases of flight of an aircraft traveling from one airport to another. We considered an aircraft scheduled for IAH airport from DCA airport. Different support tools that guide and monitor aircraft transit via the U.S. National Airspace System (NAS) where introduced by the Free Flight Program (FFP). Figure 1 shows a pictorial view of the point of application of the different FFP support tools applied at each phase of flight. These FFP automation tools include: User Request Evaluation Tool (URET), Traffic Management Advisor (TMA), Passive Final Approach Spacing Tool (FAST), Surface Management Advisor (SMA), Collaborative Decision Making (SMA), and Controller Pilot Data Link Communications (CPDLC) [11, 12]. Air traffic controllers and the aircraft pilot must interact effectively so that aircraft can efficiently and safely travel from one location to another.

For illustration purpose, we explain each phase using an aircraft that departs DCA (origination) en route to IAH (destination), which must observe takeoff, departure, en route, descent, approach, and landing phase of flight.

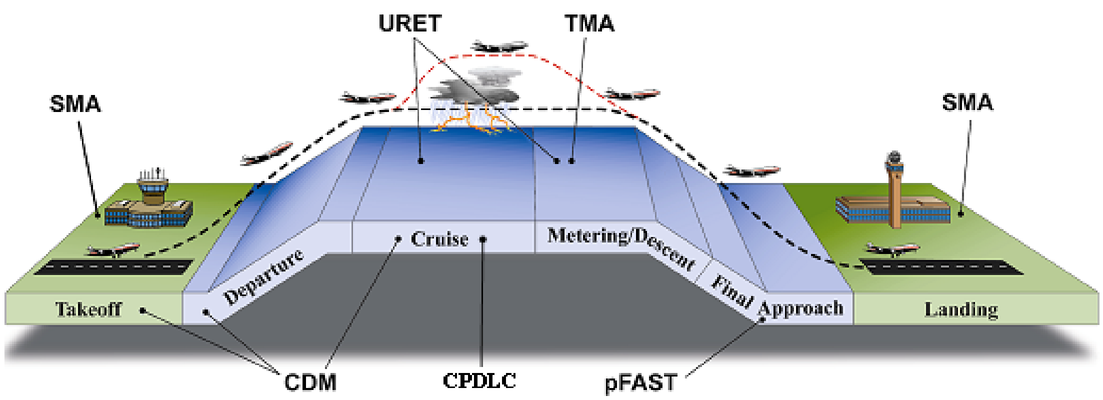


Figure 1. Free Flight Program Supportive Tools

Takeoff Phase

The aircraft operating on Instrument Flight Rule (IFR) flight plan should receive an air traffic control (ATC) clearance that specifies the air route and initial altitude that are to be used on the flight. The pilot must then switch to the DCA Air Traffic Control Tower (ATCT) radio frequency. Next, the DCA tower controller issues clearance for takeoff when he/she sees that the runway is safe for takeoff. Tower controllers visually (or use the Surface Radar Tool during period of low visibility) determine the appropriate airport conditions, and safe separation between aircraft during takeoff. After the aircraft has taken off the runway, the DCA tower controller monitors the aircraft until it is 4 to 5 miles away from the airport. At this point, the DCA tower controllers hand off the aircraft to the DCA departure TRACON controllers.

Departure Phase

Once airborne the aircraft sends an encoded signal to the DCA TRACON radar system where the information is displayed in the form of data tag on the radar scope. The data tag views the aircraft's vital information: altitude, speed, call sign and destination airport. The DCA TRACON departure controllers monitor the aircraft through the local TRACON terminal airspace to the departure gate. Note that the DCA TRACON airspace expands to about 50 miles from DCA airport and that the United States NAS has 184 TRACONs. Upon reaching the departure fix, the TRACON departure controller advises the pilot to switch to the Center Controller's radio frequency and then hands off the aircraft to the Washington Center Controllers (ZDC).

En Route Phase

The en route system of the air traffic control is a part of NAS devoted to controlling IFR aircraft between the terminal area of origination and the terminal area of destination. The Air Route Traffic Control Center (ARTCC) is sub-divided into Sectors. Each sector has two sector controllers managing air traffic. Aircraft is handed off from one sector controller to the other as they transit the airspace en route to its destination. ARTCC vectors aircraft to ensure adequate separation of air traffic, and also direct the aircraft along its assigned route. At about 200 nmi from IAH airport, the aircraft in the illustration passes through the arrival arcs as shown in Figure 2. Now that the destination of the aircraft is within the Houston sector center, the local Center Sector Controller (ZHU) will descend, re-direct, and hand over the aircraft to the local IAH TRACON when it's 50 miles from IAH.

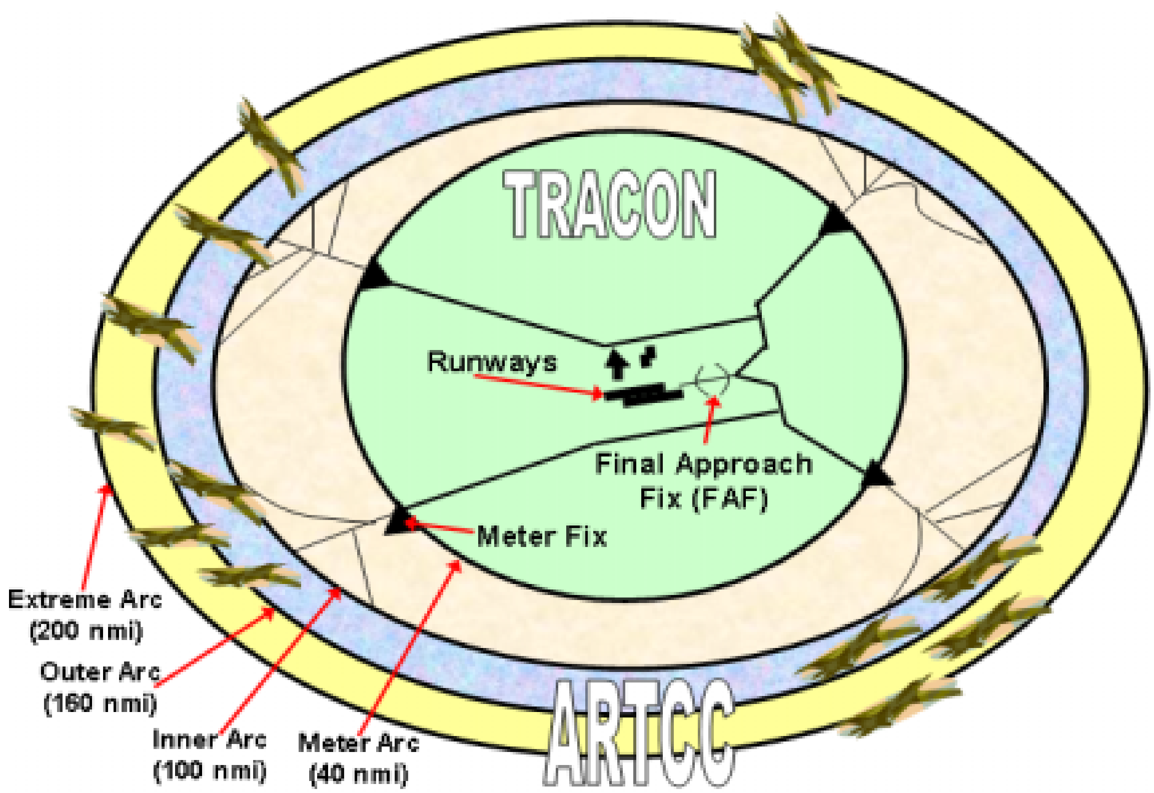


Figure 2. Arrival Arcs

Descent Phase

When the aircraft comes within a couple of hundred miles of IAH, the ARTCC will direct it to begin a descent to a specified lower altitude. Usually, the TRACON management team co-ordinates a smooth flow of arrival into the TRACON airspace. The Center controller maintains a safe separation of aircraft while directing each aircraft from a higher altitude to a lower altitude. Here, the center airspace is further sub-divided into high altitude sectors ($\geq$24000 ft) and low altitude sectors ($\leq$23000 ft). The Center Controllers direct the aircraft to a meter fix that channels arrival traffic to IAH using a given north, south, east, or west flow. Controllers at the ARTCC merge aircraft along these routes, provide sequencing and adequate separation from other air traffic, and transfer control to the Approach Controllers (IAH TRACON) at the meter fix.

The center controllers are able to view aircraft's information via their data tag. Here, the data tag provides information such as call sign, altitude, longitude, speed, departure and destination airports, departure time, and Scheduled Time Arrival (STA) of an aircraft. We observed that, at lower altitude, majority of arrival aircraft to IAH passes through DAYBO, MARIT, STROS or BUHOL meter fixes depending on type of arrival flow. Figure 3 shows a view, obtained from Flight Explorer Professional Edition 5.0b, of aircraft that are in-flight (blue aircraft) en route to IAH and those that have landed at IAH airport (white aircraft).

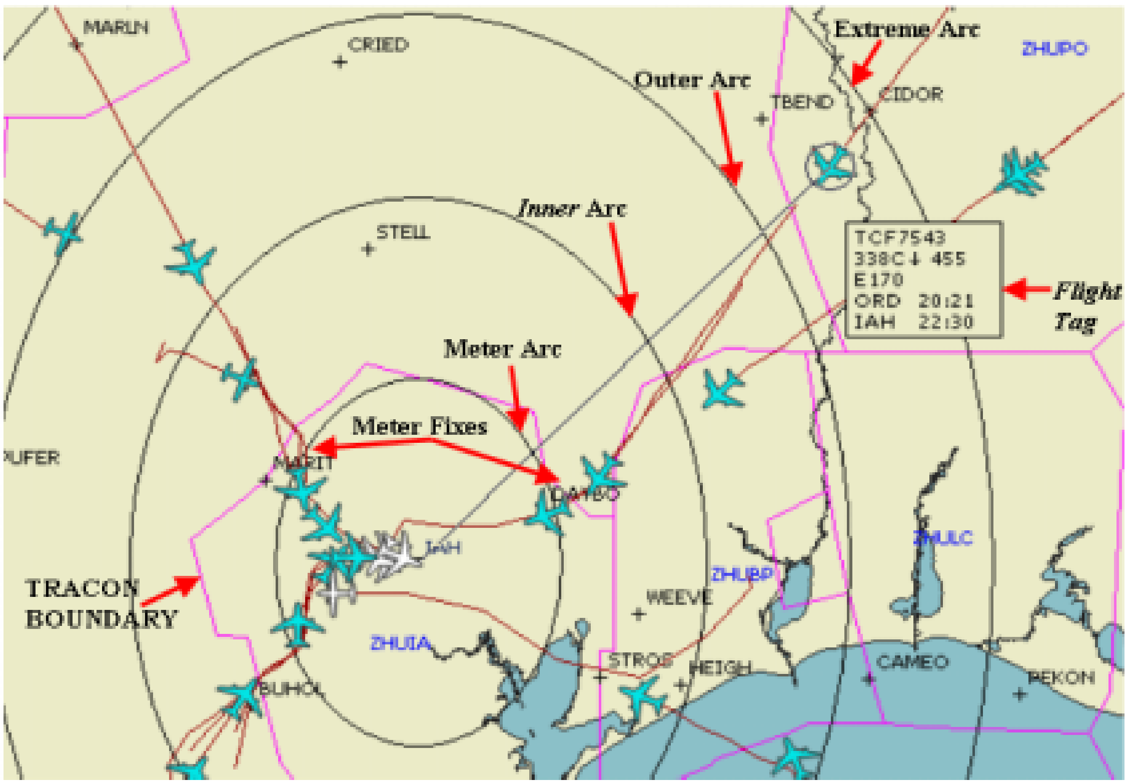


Figure 3. IAH Arrival Approach Paths and Fixes from Flight Explorer

<u>Approach Phase</u>

After the Approach Controllers (IAH TRACON) have established communication with the aircraft, then, approach control services are provided to the aircraft. The IAH TRACON instructs the pilot to fly along specific route, using different fixes, NAVAIDs and vectors. The IAH TRACON maintains a safe separation of all aircraft being directed into a smooth flowing line of air traffics on approach to the IAH runways. The IAH TRACON hands off control to the IAH airport local controller (IAH ATCT), when the aircraft is in final approach course, i.e. at about 10 nautical miles from the IAH. On final approach path the minimum mile-in-trail separations depends on both aircraft weight class and landing order as determined by the FAA's wake vortex safety rules shown in Table I [13]. Usually, a minimum horizontal distance of 5 to 6 nautical mile separation is maintained between aircraft depending on aircraft engine type and weight class (wake vortex).

Table I. Minimum distance separation matrixes for aircraft on final approach path

	Trailing Heavy Jet	Trailing Large Jet	Trailing Large Turboprop
Lead Aircraft Heavy Jet (747, DC-10)	4.0 nm	5.0 nm	5.0 nm
Lead Aircraft Large Jet (MD 80, 737)	2.5 nm	2.5 nm	2.5 nm
Lead Aircraft Large turboprop (AT 42, King Air)	2.5 nm	2.5 nm	2.5 nm

Landing Phase

At about 10 nautical miles away from IAH, the IAH TRACON transfers radio communication to the IAH tower controllers. A tower controller issues landing (or take-off) clearance to arrival (or departure) aircraft, updates each pilot with latest weather conditions, monitors proper spacing between landings, and directs pilot to an exit taxiway upon landing. When the aircraft has landed, the local tower controller directs it to the appropriate exit taxiway. Now, the pilot is then advised to change radio communication to the ground controller, who will direct the aircraft to appropriate terminal gate without interfering with active runways. The ground controllers use the Airport Surface Detection Equipment (ASDE) to monitor all vehicular movement on the airport ground. The aircraft is said to have reached its destination once it's parked at the airline gate.

B. The Traffic Management Advisor (TMA) System Description

The TMA is a support tool and has time-based strategic planning capabilities which provide the Traffic Management Coordinators (TMC) and Center controllers the ability to effectively manage the capacity of a demand impacted airport. TMA comprises of trajectory prediction, traffic visualization, controller arrival flight sequencing, constraint-based runway scheduling, and delay advisories. The TMA hardware constitutes the operational air traffic control system from which the TMA receives various entries such as aircraft flight plan and track data. These data pass through the communication manager (CM) for distribution to the prediction, visualizing and scheduling processes.

The Estimated Time of Arrival (ETA) data are used with Air Traffic Controllers' constraints to generate Scheduled Time of Arrivals (STA). Finally, the CM also transmits STA and ETA information back to the operational ATC HOST computer in the form of aircraft sequence, scheduled meter fix, delay advisories and outer metering arc crossing times on controllers plan view display (PVD). A detailed description of TMA prediction accuracy performance measurements can be found in [14], and trajectory synthesis in [15].

The timeline graphical user interface (TGUI) and the plain view graphical user interface (PGUI) both enhance TMA's capability to display various graphical features that improve situational awareness while accepting inputs from the Traffic Management Coordinators and controllers. These graphical features include traffic count overlays, data degradation alert, rush alerts, timelines, load graphs, plan view displays, sequence lists, traffic count overlays and other text overlays.

1. Timeline Graphical User Interface (TGUI)

The TGUI is the traffic management controller's (TMC's) main interface of the TMA tool. TGUI provides the means by which the TMC configures the TMA scheduler, and provides situational awareness to the TMC in the form of timeline, textual data, and load graph. The TGUI can accept sets of TMC input that are relevant for FAST operations, such as airport runway selection and landing configuration requirements. The timeline displays its own time scale and reference point type. A reference point type may be a runway threshold, final approach fix or meter fix. The abbreviations below the timeline indicate the reference point type, such as the meter fix indicated by the green MF**.** The timeline shown in Figure 4 displays the ETAs along the left side and the STAs along the right side of the timeline.

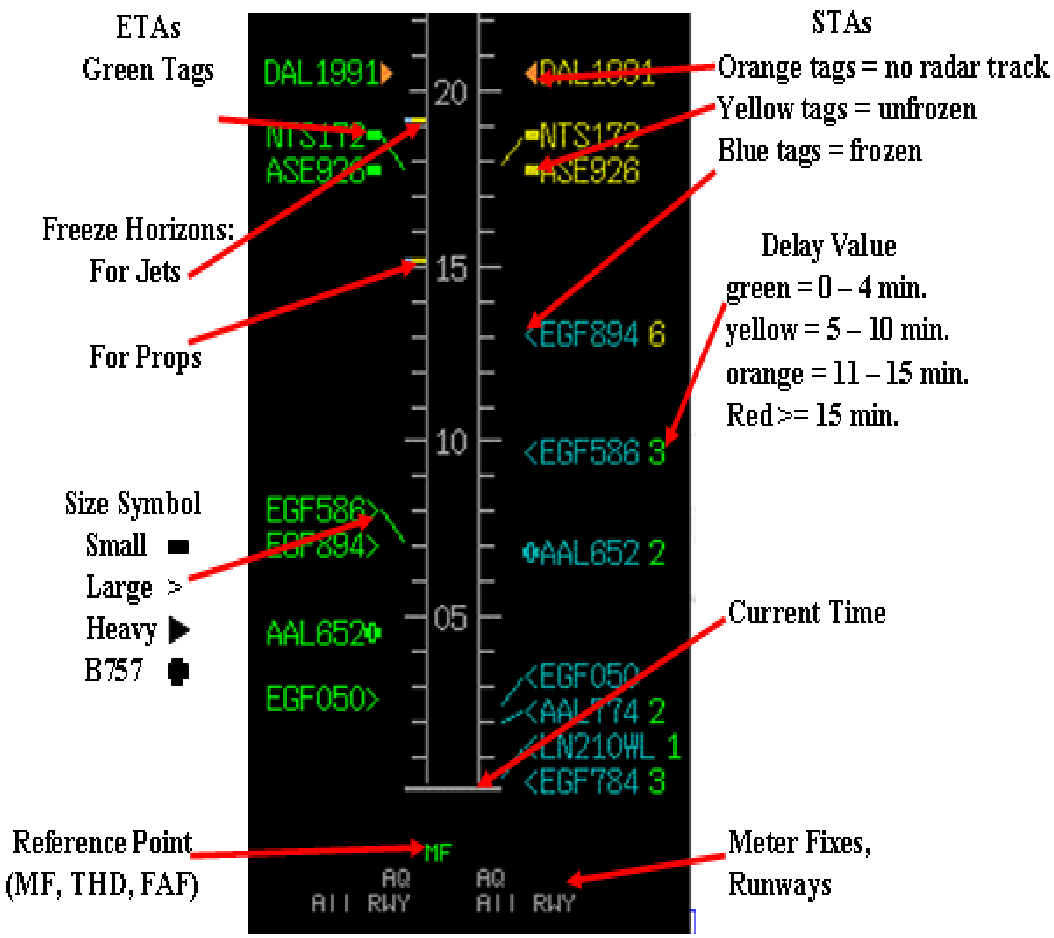


Figure 4. TMA TGUI Timeline

2. Plan view Graphical User Interface (PGUI)

The main entries to the PGUI are aircraft plan and track data; descent advisories, conflict prediction, and direct-to information; developer-requested debugging information; ETA's and STA's runway assignments and sequence numbers; and responses to user requests, such as flight plan, RA routes to be displayed for a specific aircraft. The PGUI processes weather information received from the weather daemon, only for the purpose of displaying to the user. Figure 5 shows a view of the PGUI which displays the altitudes, speed, IDs, tracks, and heading of arriving traffic. Shown in the figure is the arriving traffic over the Bridgeport (BPR) meter fix destined for Dallas / Fort Worth airport (DFW) at Fort Worth ARTCC.

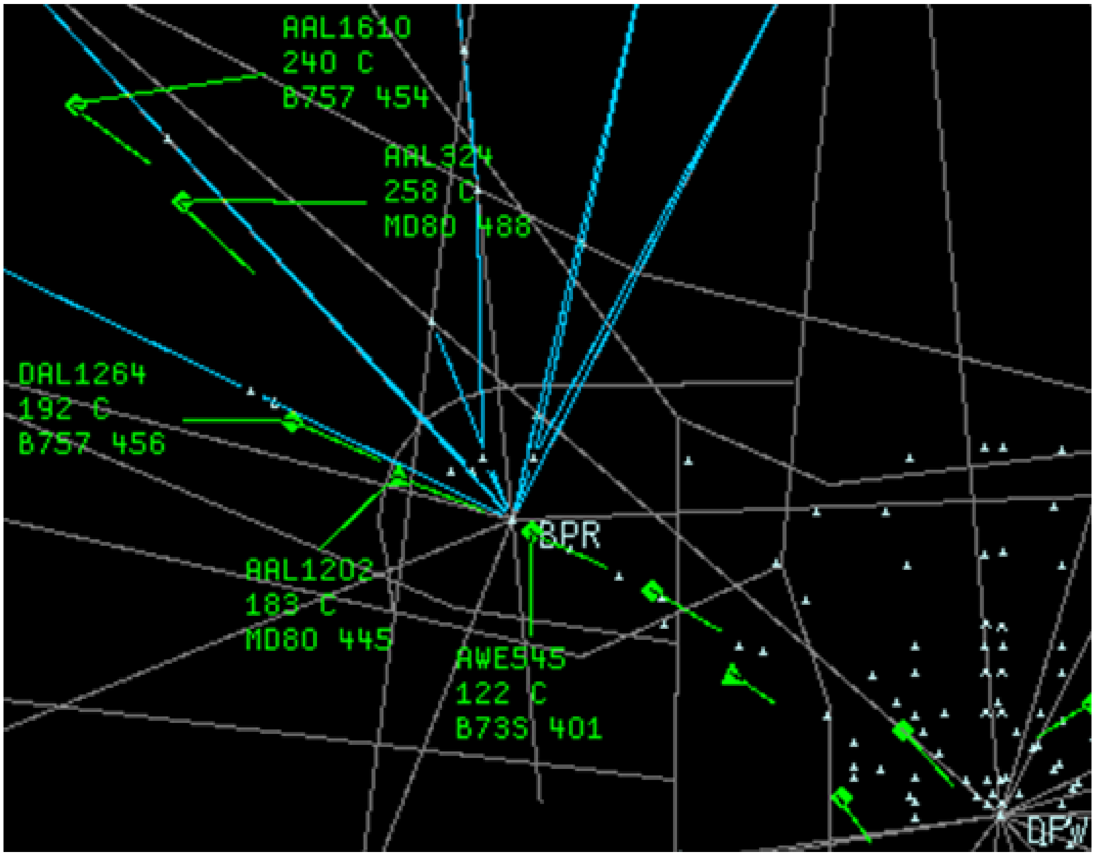


Figure 5. Aircraft Track on the TMA PGUI

3. Load Graphs

Another significant TMA feature that greatly improves situation awareness is the Load Graph. The load graph is reconfigurable; thus, it shows both present and future traffic flow to the different reference points. Figure 6 shows a load graph for traffic flow to DFW airport. The vertical axis of the figure above represents the number of aircraft in a 10 min. period while the horizontal axis represents the number of minutes after the hour. The red line shows the airport acceptance rate (AAR) that has been set by the TMC via the TMA tool. The figure shows that the AAR has been set at 18 aircraft per 10 minute period (108 aircraft per hour). The green line depends on ETA data and shows the expected traffic demand in 10 min periods. The figure shows the expected demand peaks of 33 aircraft at a particular 10 min bin (198 aircraft per hour). TMA's scheduling algorithms compute and plan arrivals to DFW based on current airport acceptance rate. We notice that the TMA scheduling algorithm has scheduled aircraft to come as close as possible to the desired ARR without exceeding it. Therefore, the demand decreases far in the future so that the number of planned arrivals does not violate the current AAR.

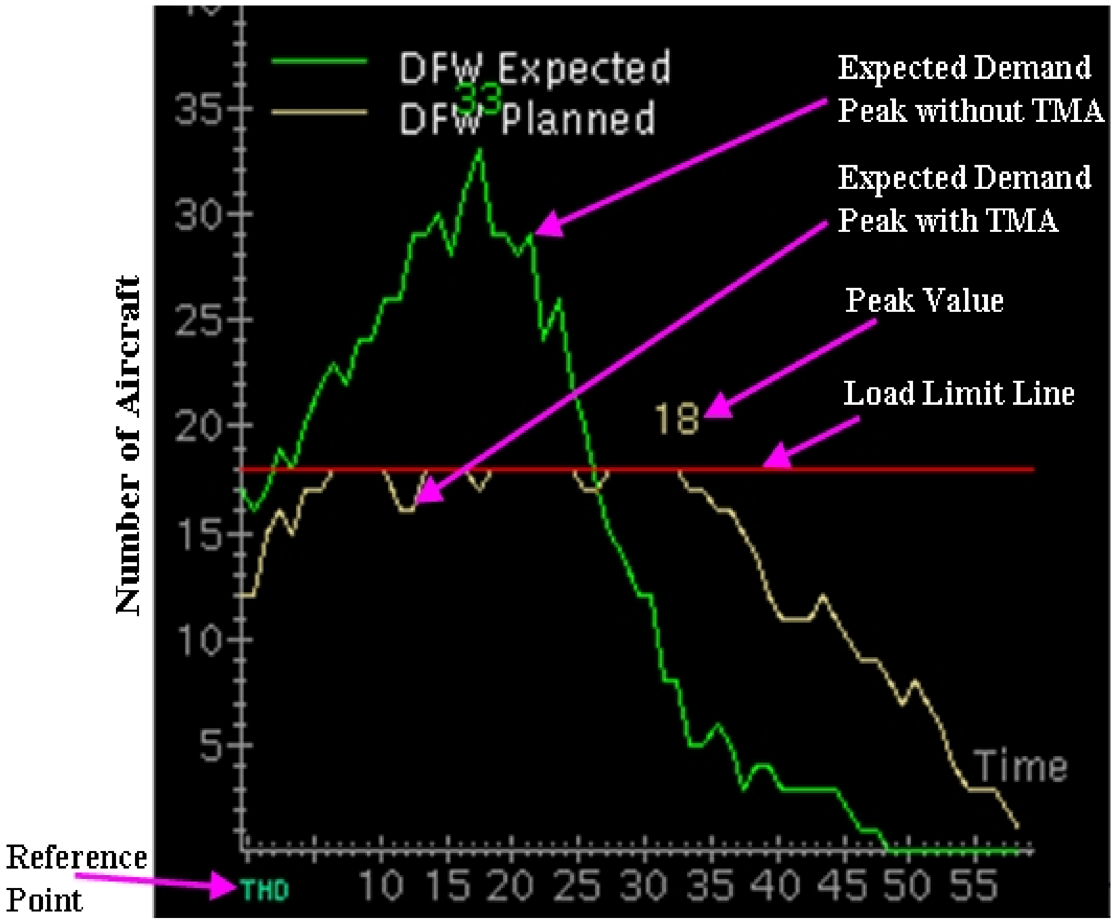


Figure 6. TMA Load Graph

4. TMA Operational Benefits

TMA is applicable for airports where arrival demand regularly exceeds capacity. The deployment of TMA at selected demand impacted airports during FFP1 and FFP2 has yielded the following improvements:

- TMA provided increased efficiency of arrival sequence by smoothing of arrival flows, lessening arrival delays, and reduced no-notice holding
- TMA provided air traffic controllers more information on airport arrival demand and available capacity for making decisions on aircraft spacing.
- TMA has improved sequencing plans and optimal runway balancing, and increased arrival and departure rates.

- TMA provided the air traffic controllers the capability to balance runway use and sequence aircraft according to user preferences and airport capacity.
- TMA has helped reduce the application of miles in trail restrictions and increase communication between the En Route Centers and Terminal Area.

In general, most traffic controllers claimed that TMA helped reduce holding, flight times, and departure delay for flights that took-off from airports within an ARTCC (internal departure) en route to a TMA adapted airport. Although, TMA and time-based metering have not been able to completely eliminate holding, control centers have reported that the shared situation awareness provided by TMA has helped eliminated the "no-notice" holding.

C. Deployment Schedule of the Traffic Management Advisor (TMA)

The TMA is currently operational at eight Air Route Traffic Control Centers (ARTCCs). At each control center, TMA calculates arrival schedules of flights to the local airport [16, 17]. TMA was first implemented at the ZFW site in June 1996, where it was observed that it reduced delay by 70 seconds per arriving aircraft during rush arrival periods. It was also found that the Terminal Radar Approach Control (TRACON) increased the Airport Acceptance Rate by 5% during the same period. The TMA system deployed at the Los Angeles Center (ZLA), Houston Center (ZHU), and Atlanta Center (ZLA) has additional capability that permits further coordination of flights in an adjoining center's airspace via the use of the Adjacent Center Data Feed (ACDF). At the Minneapolis Center (ZMP), the initial daily use of TMA for Minneapolis St. Paul airport arrivals began in June 2000. The MSP TRACON traffic managers observed an increase of the AAR by 0.7 (visual) and 1.4 (instrument) arrivals per hour**.**

TMA daily use at Denver Center (ZDV) for Denver airport (DEN) arrivals began in September 2000. An assessment of TMA operations at DEN during poor weather showed that the tool increased arrival rate by 1 (visual) and 2 (instrument) aircraft per hour. Active use of TMA began at Los Angeles Center (ZLA) for traffic arrivals to Los Angeles airport (LAX) in June 2001. However, time based metering test of TMA started in May 2002. Reference 23 reported a 1.5% increase in airport arrival rate during instrument conditions. Traffic Management Coordinators (TMC) began to use TMA at Atlanta Center (ZTL), in June 2001, for arrivals at Atlanta airport (ATL). TMC at ZTL found that total holding time reduced by 24% when June-August 2000 was compared with the summer months of 2002. The various TMA displays, for example the load graph, were use by the Miami TRACON controllers to make decisions about staffing, restrictions, and airport configuration. Houston Center (ZHU) is the most recent site to receive TMA for IAH arrivals. ZHU began TMA operations in June 2003. Figure 7 summarily illustrates TMA deployment at Air Route Traffic Control Center sites in the US National Airspace System (NAS).

As we can see in the figure, PHL, which is in the overlapped area of ZDC and ZNY is not currently equipped with TMA . However it is planned to deploy TMA to PHL in the near future. A part of the study therefore is to analyze characterization of the arrival flow at PHL so that it can be used as baseline with which any analysis of post-TMA can be compared. On the other hand, IAH in ZHU is currently fully TMA operational. And the IAH operational data of arrival flow in pre-TMA and post-TMA were available during the project period. We spent all most of the project period in the comparisonal analysis of pre- and post-TMA characterization of IAH arrival traffic flow. In the analysis, we focused first on overall arrival characterization and second, on the en-route traffic flow characterization.

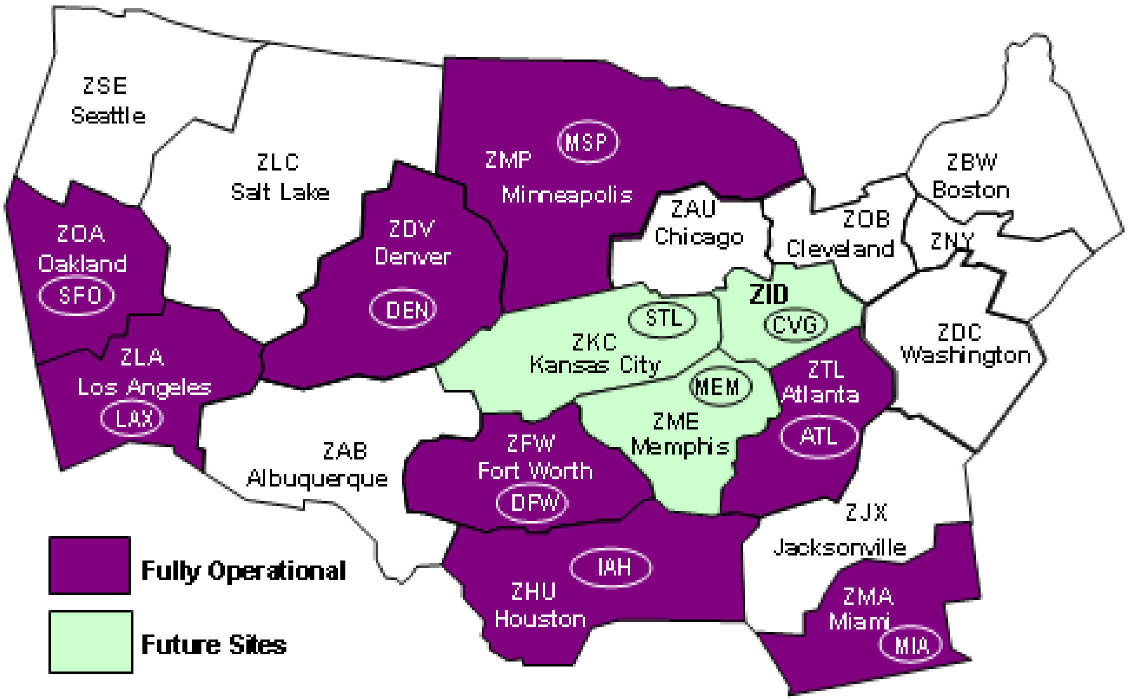


Figure 7. TMA Deployment

In chapter II, we discuss the baseline analysis of PHL arrival flow. This study was conducted at the very first phase of the project in which analysis training at FAA Free Flight Office and visits to centers and TRACONs were also a big part of the project.

Chapters III and IV discuss the pre- and -post TMA analysis in IAH based on the data provided by FAA. The data from FAA was gradually updated and revised since the first data did not involve information we need to properly assess the benefit of TMA in IAH. The data in the analysis is still not complete, but we could manage to bring assessment results in two aspects. One is the overall arrival delay statistics and the other is the delay statistics only in the en-route domain. The overall arrival delay for TMA assessment is the natural approach with the given data and the chapter III discusses this aspect. The overall delay however contains a problem: the uncertainty in departure airport. Since the data does not provide any delay or problem in departure we simply assume that the departures were on time. However this assumption is not appropriate. To eliminate this departure uncertainty and for a better assessment of TMA, we picked en-route travel time statistics. Chapter IV deals with this aspect of en-route domain delay statistics for TMA assessment.

In chapter V, we conclude our project and also discusses about future work for TMA assessment and modeling approach.

II. Baseline Study of PHL on Arrival Traffic Flow

This chapter is result of the baseline investigation of the status of the Philadelphia TRACON. The study is focused on the following two areas:

1. Arrival (rate and delay) statistics both for internal and external departures, and
2. Flight times between the 200 nmi (nautical mile) arc and meter fixes, and between meter fixes and arrival airport both for internal and external flights.

A. Arrival Rate Analysis

1. Arrival Raw Data - Flight Explorer and ASPM

Most of the data used for this analysis was collected from the FAA's Flight Explorer Professional Edition software. It is an Internet-based real-time flight-tracking tool that runs under Microsoft Windows platform and allows the user to obtain information about commercial, passenger, and private flights. After configuring Flight Explorer, daily log files were generated (see Figure 8) containing, for example, all flights arrived at PHL. The second source of data was FAA's Aviation System Performance Metrics (ASPM) system, which provides information on individual flight performance on airport efficiency, arrival and departure rates. ASPM was mostly used for comparing its mean actual arrival rate metric results to the experimental mean actual arrival rate analysis.

107	9/14/2004	00:45:03	1003	Aircraft arrived	USA1686	ATL/PHL	ATL	PHL	E170	23:10	00:44
108	9/14/2004	00:45:03	1010	Aircraft entered area	USA872	PHL 150	PIT	PHL	B733	00:24	01:13
109	9/14/2004	00:45:03	1009	Aircraft near destination	JIA2357	DAY/PHL	DAY	PHL	CRJ2	23:40	00:56

Figure 8. Section of flight explorer's log file

As shown in Figure 8, data stored in log files from Flight Explorer is arranged as a collection of individual records in Microsoft Excel format. A typical log file usually contains an average of 7000 records for a day. To manually examine such a large volume of data was stressful and time consuming. Thus, a better methodology was needed to be able to retrieve the desired data as quickly as possible from the generated log files. After much research and planning, a web-based data-mining tool was developed. The Flight Explorer Data-Mining Tool (FEDT), so named, performs dynamic operations on the log files.

FEDT's operational platform is a free software package entitled *phpdev*. The *phpdev* is a bundle of PHP, Apache, MySQL, PERL, and phpMyAdmin, preconfigured to run on the win32 platform. The implementation of FEDT was broken down into three simple tasks. The first task was to design a GUI interface for performing all necessary operations on the log files, the second task was to populate all the generated log files into one major database source, and the third task was to implement dynamic interaction between the GUI and the database. PHP scripting was mostly used to accomplish the first and third tasks. The second task, however, required several steps. The log files, by default, were saved with a *.csv* extension in Flight Explorer. From this format, the files were converted into Excel file format, and then imported to an Access database. Finally, they were exported to FEDT's MySQL database.

2. Analysis of Arrival Data

In order to perform the mean actual arrival rate analysis at PHL certain factors were taken into consideration. Initially, a day was randomly chosen and analyzed for an overall arrival rating. This was done by simply prompting FEDT for a collection of all flight arrivals for that particular day and counting the number of arrivals in each fifteen minute segment.

In order to obtain more meaningful results, however, a different approach was needed. Using the 200nmi radius, flight arrivals were divided into internal and external arrivals. Flights originating from airports within the 200nm radius were defined as *internal flights*, and flights originating outside of the 200nmi radius were defined as *external flights*. Furthermore, the different types of airports were taken into consideration, namely, *pacing*, *major*, and *other*. According to the FAA, *pacing* airports are considered as carriers of the largest traffic load (approximately 108 US airports), the *major* airports as the largest airports categorized by passenger enplanement (approximately 500 US airports), and *other* as all other existing US airports (over 17,000). Using these two factors, the internal mean arrivals and external mean arrivals were calculated.

There were several reasons why this analytical approach was chosen. The first reason was to observe the proportionality between the daily internal and/or external arrival ratings to the overall arrival rating. Secondly, by calculating internal and external arrival ratings, internal and external flight arrival pattern(s) could be analyzed towards the main objective of enhancing air space traffic. Lastly, these flight arrival assessments could be taken into consideration in the deployment of the TMA-MC system.

The focus of the arrival rate analysis for PHL was centered around the first week of the months of October and November (i.e., 10-04-04 to 10-10-04, and 11-01-04 to 11-07-04). Figure 9 shows how resulting statistic from the raw data was obtained and organized.

Number of Flight Arrivals to PHL								
	Internal			**External**				
Time Range	**Pacing**	**Major**	**Total**	**Pacing**	**Major**	**Total**	**Other**	**Overall**
00:00:00 - 00:15:00	0	0	0	4	0	4	2	6
00:15:00 - 00:30:00	0	0	0	4	0	4	1	5
00:30:00 - 00:45:00	1	0	1	8	0	8	0	9
00:45:00 - 01:00:00	1	3	4	8	0	8	1	13
01:00:00 - 01:15:00	3	2	5	9	1	10	1	16
01:15:00 - 01:30:00	0	0	0	5	1	6	4	10
01:30:00 - 01:45:00	0	1	1	5	1	6	0	7
01:45:00 - 02:00:00	2	0	2	5	0	5	0	7
02:00:00 - 02:15:00	0	0	0	2	0	2	0	2
02:15:00 - 02:30:00	0	0	0	4	0	4	0	4
02:30:00 - 02:45:00	0	0	0	2	0	2	0	2

Figure 9. Resultant Statistics from Raw Data

Based on the analysis performed for the two weeks mentioned above, the following general observations were made:

a. Most arrivals to PHL were between 12:00am to 6:00am and from 10:00am to 11:59am.
b. There were more external flights (i.e., outside of the 200nmi radius) arriving to PHL.
c. Internal flight arrivals (i.e., inside of the 200nmi radius) to PHL were almost equally distributed between pacing and major airports.
d. Externally, more flights originate from pacing airports by a large margin.
e. There were other internal (i.e., inside the US) and external (i.e., outside of the U.S) flights arriving into PHL, but they were neither major nor pacing. Observation showed the following:
   i. These internal flights originated from U.S civil airports wherein permit covers use by transit military aircrafts
   ii. These external flights originated from civil government airports, where landing fees and diplomatic clearance may be required.
   iii. Generally, flights from these civil airports followed the same arrival schedule into PHL.

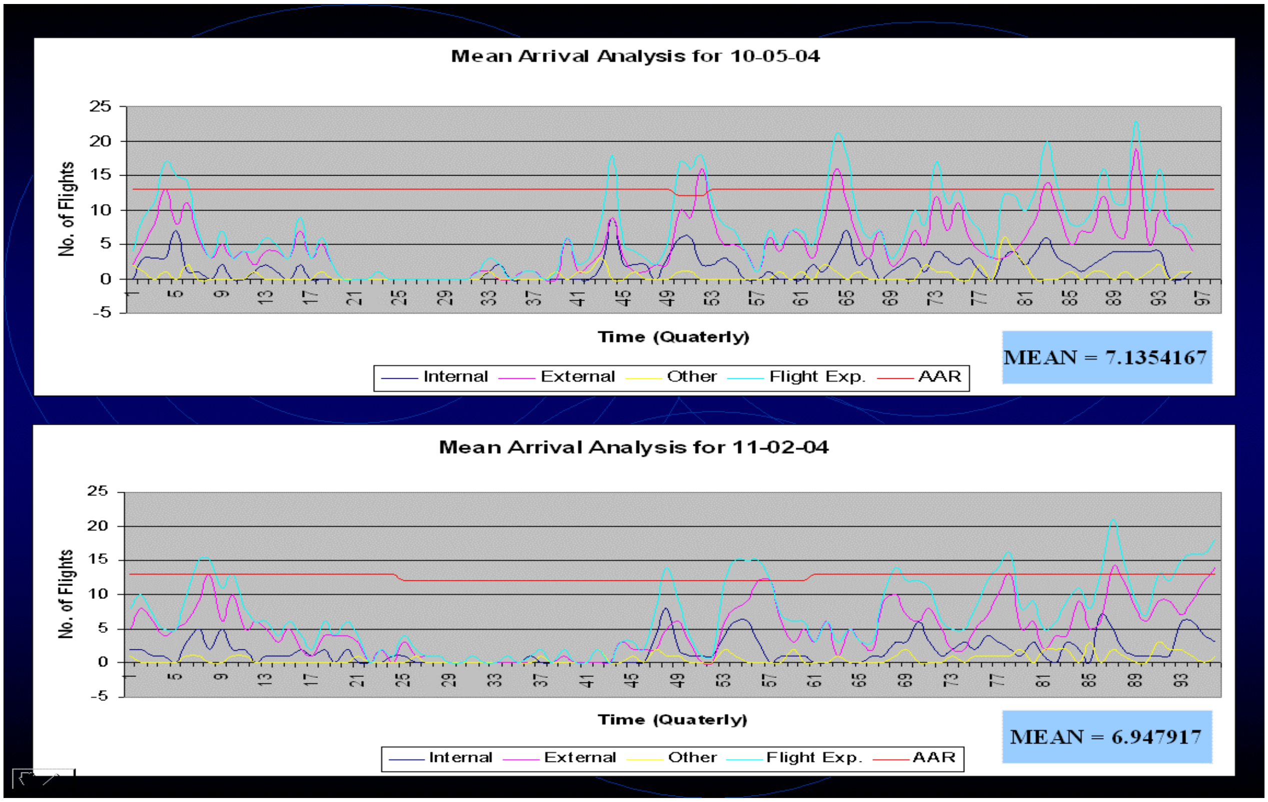


Figure 10. Arrival Rate Analysis (Nov.02, 2004)

In general, the daily traffic flow into PHL could basically be characterized by the following sample analysis taken on October 05, 2004 and November 02, 20004 (see Figure 10). Similarly, the daily arrival flow, when compared between flights from major and pacing airports, was also characterized by the graph in Figure 11. It was apparent that, in the case where flights originated from pacing airports, most flights were from the pacing airports that are located outside of the 200nmi radius. As for the case where flights originated from major airports, equal distributions of arrivals were made from both internal and external major airports.

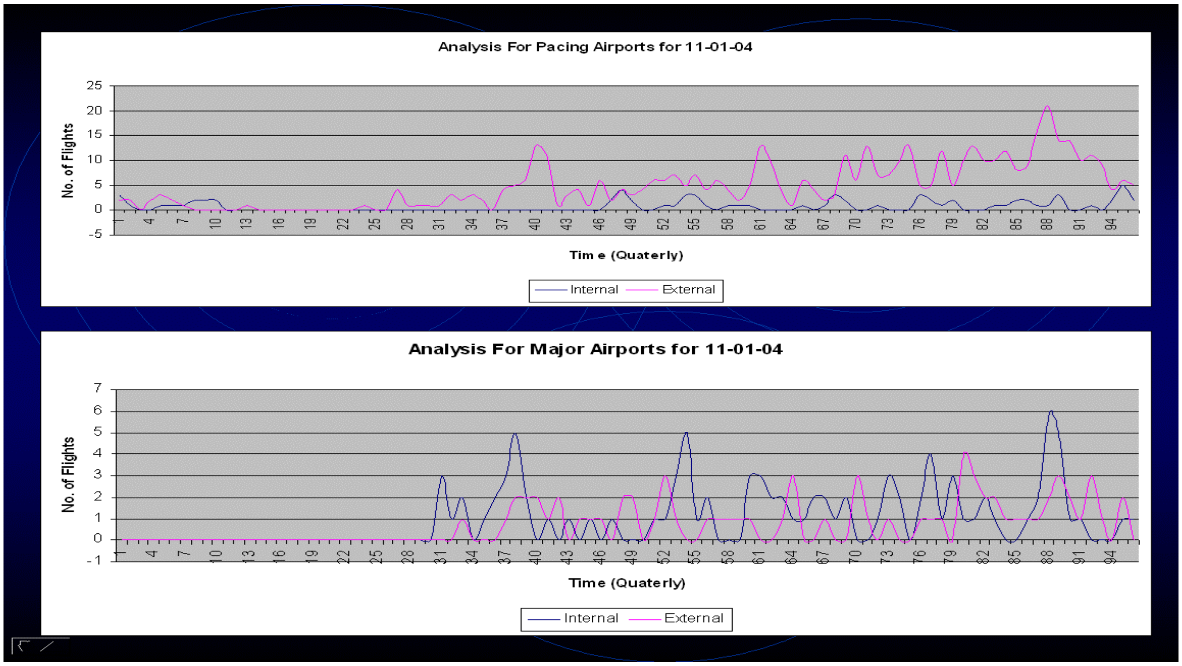


Figure 11. Arrival Rate Analysis (Nov.01, 2004)

3. Comparison of Flight Explorer and ASPM

To see how accurate the analysis was, based on the raw data collected from Flight Explorer, the resulting data was compared with the FAA's ASPM online database. Two major tools from ASPM were used for gathering ASPM data: the Airport Efficiency Tool and the Analysis Tool (see Figure 12).

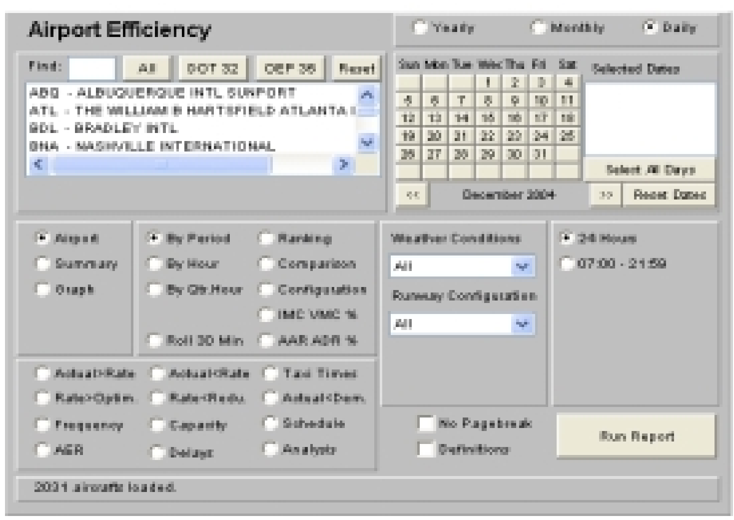


Figure 12. Snapshots of ASPM Data Analysis Tools

Comparison of the mean actual arrival rate between Flight Explorer and ASMP were performed for the first week of October and November. A sampling is shown in Figure 13.

Observation showed a high level of inconsistency between Flight Explorer and ASPM data. For example, the number of flight arrivals for every fifteen minutes were of different values. To resolve this inconsistency further research was needed. Also, several questions must be answered: Were the data retrieved from ASPM faulty, or were the data from Flight Explorer faulty? Was Flight Explorer configured correctly for recording arrivals to PHL? How often was the ASPM online database modified?

Number of Flights Arrivals For 2004-10-04										
	Internal			External				Total Arrivals		
Time Range	Pacing	Major	Total	Pacing	Major	Total	Other	Flight Exp.	ASPM	AAR
00:00:00 - 00:15:00	0	0	0	2	0	2	3	5	0	13
00:15:00 - 00:30:00	2	0	2	8	1	9	1	12	0	13
00:30:00 - 00:45:00	1	2	3	6	0	6	1	10	3	13
00:45:00 - 01:00:00	2	1	3	10	1	11	0	14	0	13
01:00:00 - 01:15:00	1	3	4	11	2	13	0	17	0	13
01:15:00 - 01:30:00	1	1	2	7	1	8	1	11	0	13
01:30:00 - 01:45:00	2	1	3	4	0	4	1	8	0	13
01:45:00 - 02:00:00	0	0	0	3	1	4	0	4	0	13
02:00:00 - 02:15:00	0	0	0	4	0	4	0	4	0	13
02:15:00 - 02:30:00	1	0	1	3	0	3	0	4	0	13
02:30:00 - 02:45:00	0	0	0	3	0	3	1	4	0	13
02:45:00 - 03:00:00	0	0	0	4	0	4	0	4	0	13
03:00:00 - 03:15:00	1	0	1	2	0	2	0	3	0	13
03:15:00 - 03:30:00	0	0	0	2	0	2	0	2	0	13
03:30:00 - 03:45:00	0	0	0	3	1	4	0	4	0	13
03:45:00 - 04:00:00	0	0	0	0	0	0	0	0	0	13
04:00:00 - 04:15:00	0	0	0	3	0	3	1	4	0	13
04:15:00 - 04:30:00	0	0	0	1	0	1	0	1	0	13
04:30:00 - 04:45:00	0	0	0	3	0	3	0	3	0	13
04:45:00 - 05:00:00	0	0	0	0	0	0	0	0	0	13
05:00:00 - 05:15:00	0	0	0	0	0	0	0	0	0	13
05:15:00 - 05:30:00	0	0	0	0	0	0	0	0	2	13
05:30:00 - 05:45:00	0	0	0	0	0	0	0	0	0	13
05:45:00 - 06:00:00	0	0	0	0	0	0	0	0	1	
06:00:00 - 06:15:00	0	0	0	0	0	0	0	0	3	
06:15:00 - 06:30:00	0	0	0	0	0	0	0	0	2	
06:30:00 - 06:45:00	0	0	0	0	0	0	0	0	0	
06:45:00 - 07:00:00	0	0	0	0	0	0	0	0	7	
07:00:00 - 07:15:00	0	0	0	0	0	0	0	0	18	
07:15:00 - 07:30:00	0	0	0	0	0	0	0	0	3	
07:30:00 - 07:45:00	0	0	0	0	0	0	0	0	1	
07:45:00 - 08:00:00	0	0	0	0	0	0	0	0	1	
08:00:00 - 08:15:00	0	0	0	0	0	0	0	0	4	
08:15:00 - 08:30:00	0	0	0	0	0	0	0	0	11	
08:30:00 - 08:45:00	0	0	0	0	0	0	0	0	17	

Figure 13. Flight Explorer vs. ASPM

It was revealed that this inconsistency problem was also experienced by other researchers. Researchers from the Massachusetts Institute of Technology Lincoln Laboratory recorded the following testimony[18]:

> *Last month we continued out examination of the completeness of the PARO input surveillance data by comparing PARO traffic counts for the 26 November 2003 against FAA traffic "Counts for Efficiency Computation" obtained from the Aviation System*

Performance Metrics Efficiency (ASPME) online database…We found that the counts derived from the PARO and ASPME sources agreed closely. (The cumulative counts for the day differed only by three arrivals.)

To fully validate the completeness and reliability of the PARO analysis, we will need to make additional comparisons of PARO and ASPM counts…In comparing data for a range of days that we downloaded on two occasions that were 22 days apart, we observed that the ASPM arrival and departure counts for efficiency computation increased significantly between the first and second downloads…Clearly, the initial posting is not as complete as the data that is available a few weeks later. The reason for this lies in the ASPM data acquisition and update process.

The same procedures outlined in the above testimony were followed and the results were amazingly the same. It was also apparent that there was inconsistency within ASPM itself. For example, when comparing its raw data with its generated graphic charts, they conflicted. The first graphical charts in Figures 14 and 15 were retrieved from ASPM. The second graphical charts were generated from Microsoft Excel, using raw data from both Flight Explorer and ASPM (also see Figure 13). Looking closely at the function graphs of ASPM (colored in blue), the two graphs do not follow the same path. This shows a conflict between ASPM's raw data and ASPM's graphic charts from the raw data.

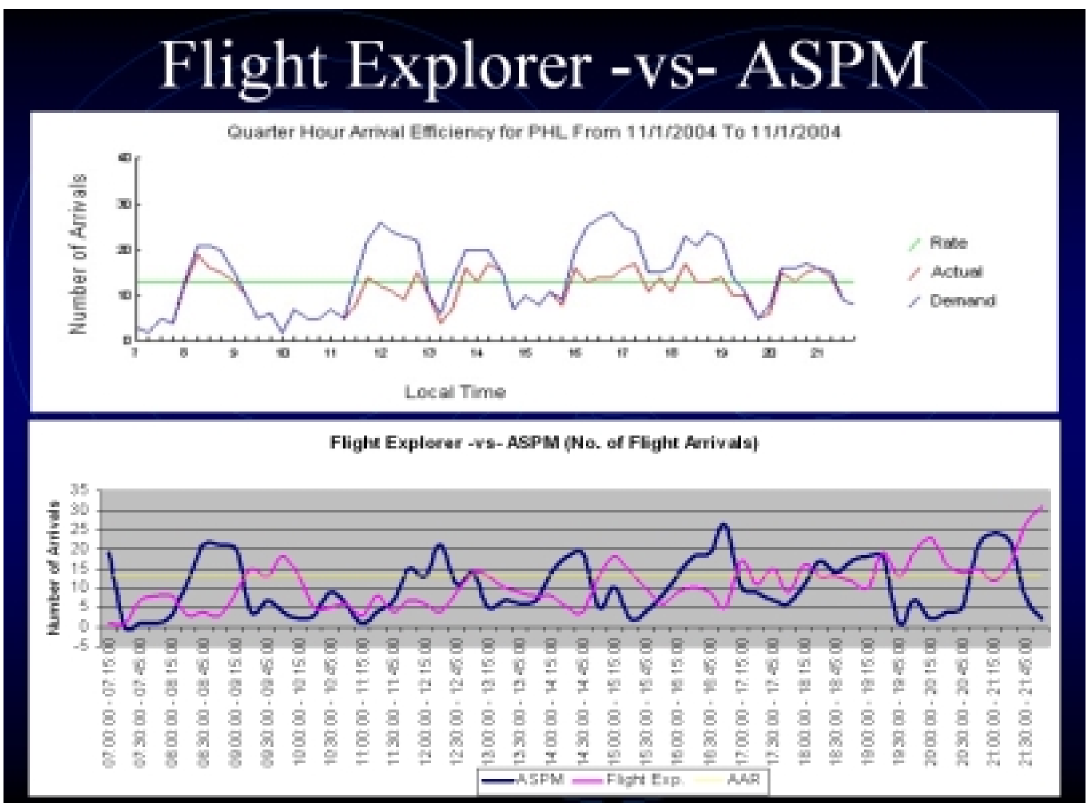


Figure 14. Flight explorer vs. ASPM (Nov.01, 2004)

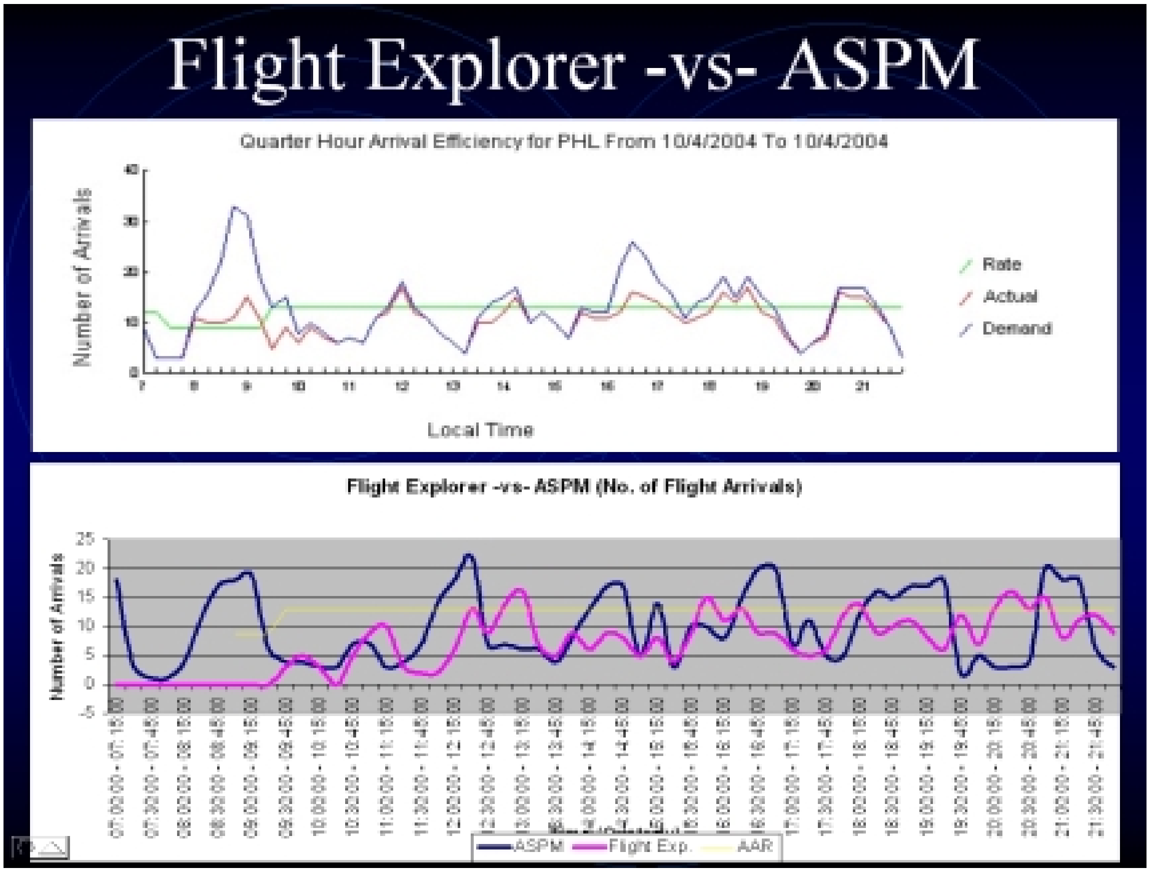


Figure 15. Flight explorer vs. ASPM (Oct.04, 2004)

It would be unreasonable to conclude that the inconsistencies between Flight Explorer and ASPM were due to the conflicts that existed in ASPM. It was also necessary to know if Flight Explorer was prone to errors. To answer this question, a simple modification was made in Flight Explorer's method of recording flight arrivals. Flight Explorer's log file setting is by default set to record flight arrivals using the 'UTC' time format. By changing this default setting to 'Local' time format, it would then be possible to see if Flight Explorer's raw data would still be consistent in the log files.

Raw data for the first week of October was recorded using the default time format. For the first week of November, however, both time formats were used. It turned out that Flight Explorer was also inconsistent. The results are shown in Figures 16 and 17.

Flight Explorer -vs- ASPM

Flight Arrival Comparison between Flight Explorer and ASPM (using 'UTC Time' Format)										
Date	Internal			External				Total Arrivals		
	Pacing	Major	Total	Pacing	Major	Total	Other	Flight Exp.	ASPM	Diff
10/4/2004	72	79	151	391	56	447	37	635	651	16
10/5/2004	83	78	161	412	61	473	51	685	712	27
10/6/2004	88	83	171	425	65	490	60	721	705	16
10/7/2004	86	78	164	429	61	490	50	704	686	18
10/8/2004	84	74	158	421	66	487	55	700	691	9
10/9/2004	67	67	134	349	53	402	51	587	551	36
10/10/2004	65	65	130	332	47	379	52	561	592	31
								Total Difference		153
Total	545	524	1069	2759	409	3168	356	4593	4588	5

Figure 16. Arrival rate comparison between Flight explorer and ASPM (UTC time format)

Flight Arrival Comparison between Flight Explorer and ASPM (using 'Local Time' Format)										
Date	Internal			External				Total Arrivals		
	Pacing	Major	Total	Pacing	Major	Total	Other	Flight Exp.	ASPM	Diff
11/1/2004	71	94	165	470	70	540	140	779	690	89
11/2/2004	60	48	108	311	48	359	100	539	744	205
11/3/2004	85	91	176	427	64	491	48	715	748	33
11/4/2004	74	77	151	371	63	434	48	633	703	70
11/5/2004	88	79	167	443	64	507	49	723	734	11
11/6/2004	73	78	151	376	49	425	42	618	599	19
11/7/2004	59	67	126	339	55	394	50	570	657	87
								Total Difference		514
Total	510	534	1044	2737	413	3150	477	4577	4875	298

Flight Arrival Comparison between Flight Explorer and ASPM (using 'UTC Time' Format)										
Date	Internal			External				Total Arrivals		
	Pacing	Major	Total	Pacing	Major	Total	Other	Flight Exp.	ASPM	Diff
11/1/2004	71	81	152	384	59	443	50	645	690	45
11/2/2004	77	84	161	393	60	453	53	667	744	77
11/3/2004	84	90	174	427	64	491	48	713	748	36
11/4/2004	74	76	150	371	63	434	48	632	703	71
11/5/2004	88	79	167	445	64	509	49	725	734	9
11/6/2004	73	78	151	377	49	426	41	618	599	19
11/7/2004	60	66	126	337	54	391	51	568	657	89
								Total Difference		345
Total	527	554	1081	2734	413	3147	340	4568	4875	307

Figure 17. Arrival rate comparison between Flight explorer and ASPM (local time format)

B. Arrival Delay Analysis

1. Overview of delay

Mean arrival delay analysis is a key factor in TMA performance assessment. Minimizing mean arrival delay through atomization directly improves three of the five desired outcomes set by FAA:

- Efficiency
- Predictability
- System Productivity

Arrival delay is a sum of contributions of delays at different stages. The following are causes of the delay:

- Gate delay (departure airport)
- Taxi-out delay(departure airport)
- En route delay(On air delay)
- Terminal delay(Arrival airport)
- Taxi-in delay(arrival airport)

There are several causes of the above mentioned delays, weather condition being the major factor. A great deal of delay is introduced when arrival and departure demand exceeds Airport arrival rate (AAR) and airport departure rate (ADR) respectively. This condition occurs when one or more of the following conditions are encountered:

- Bad Weather
- Demand fluctuations
- Heavy traffic volume
- Equipment failure
- Runway closure

After the tragic event of September 11, 2001, delays caused by security measures are becoming more than delays caused by heavy volume. On top of the above mentioned delay sources, PHL encounters delays caused by limitation of runways which directly lowers the AAR and ADR of the airport.

2. Delay analysis

Delay analysis was done for all flights arriving at PHL on daily bases. To identify and understand the traffic flow differences, analysis was performed for Internal and External flights separately. As mentioned before, internal flights are those whose departure airport is within the physical 200nmi radius of PHL airport and External flights are those departing from out side the 200nmi radius.

The following graphs (Figures 18 -20) are visual representations of flight data from October 04, 2004. In the first one of these graphs, even though having many parameters in one graph makes it harder to read, it is possible to easily see the relationship between each element. Since the number of external flights is much more than the number of internal flights, the overall mean delay is highly influenced by the external mean delay. Also observed was the smaller mean delay for internal flights than external flights.

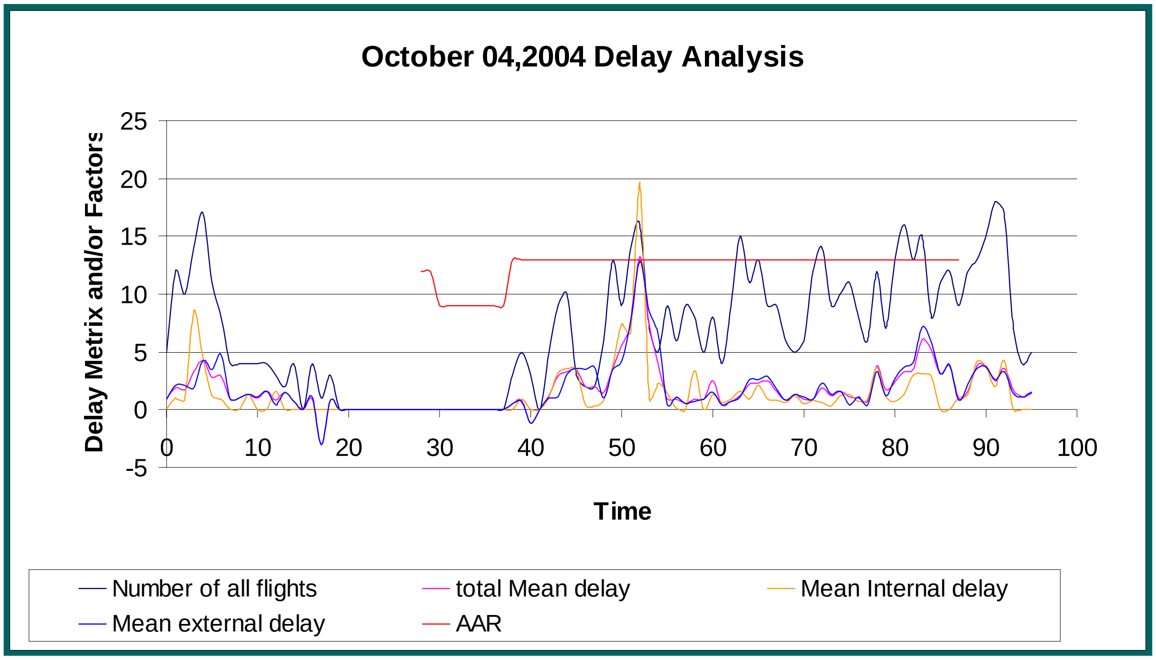


Figure 18. Overall Delay Analysis (October 04, 2004 flights)

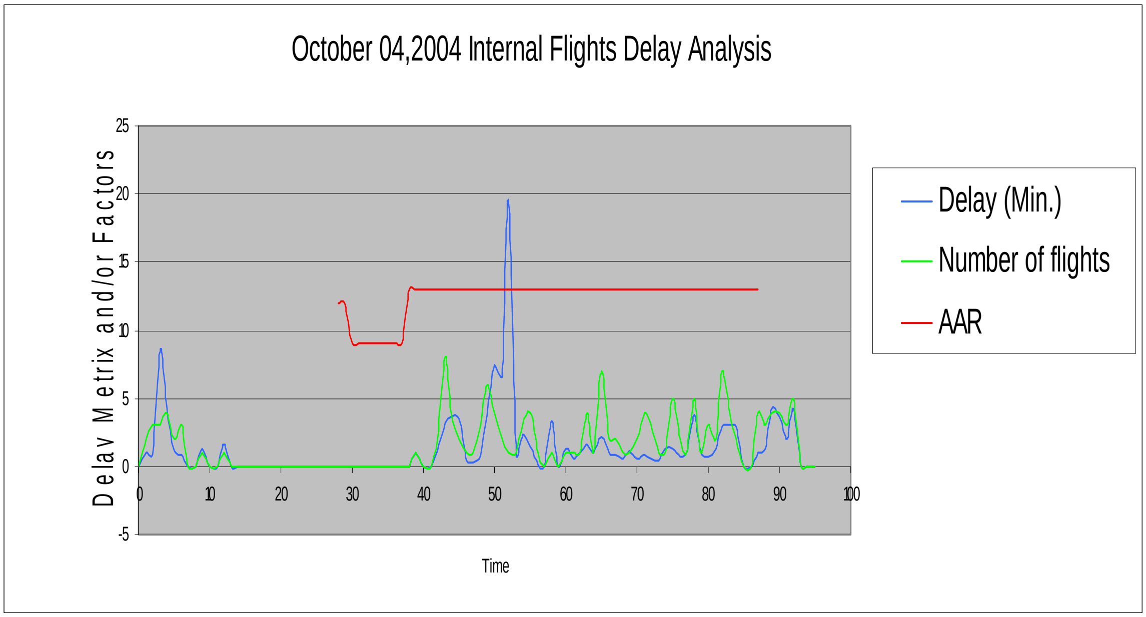


Figure 19. Delay Analysis (October 04, 2004 Internal flights)

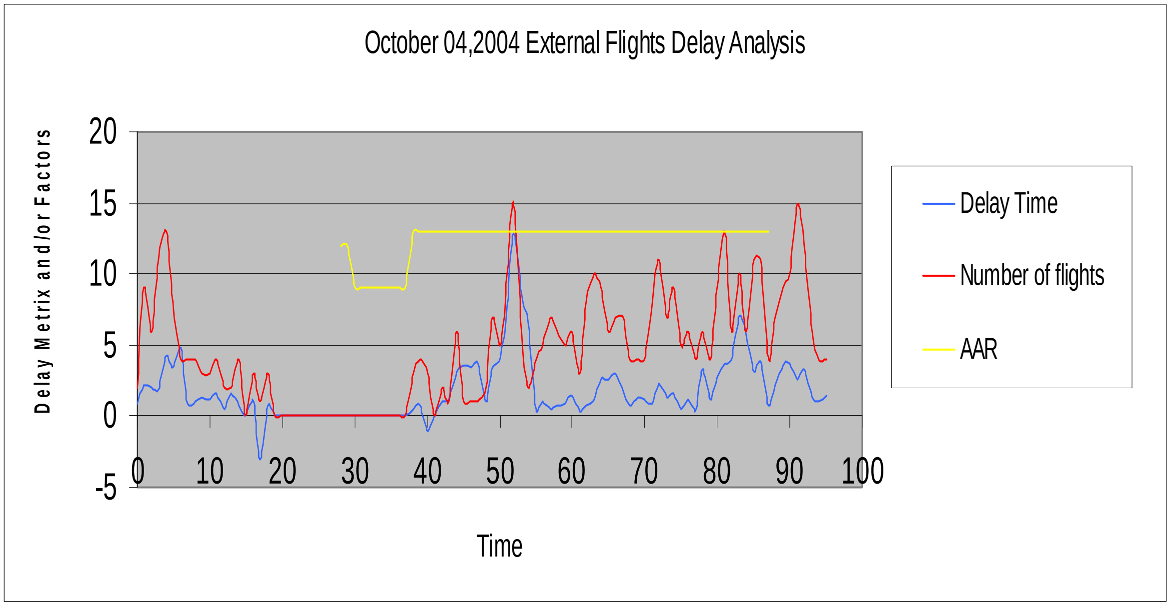


Figure 20. Delay Analysis (October 04, 2004 External flights)

The following three graphs (Figures 21 - 23) correspond to October 07 flights. The total mean delay time has a negative peak merely because the internal mean delay has a negative peak at the same location on the graph. Since the number of external flights is much higher than that of internal flights, the total mean delay is mostly influenced by events happening to the external flights.

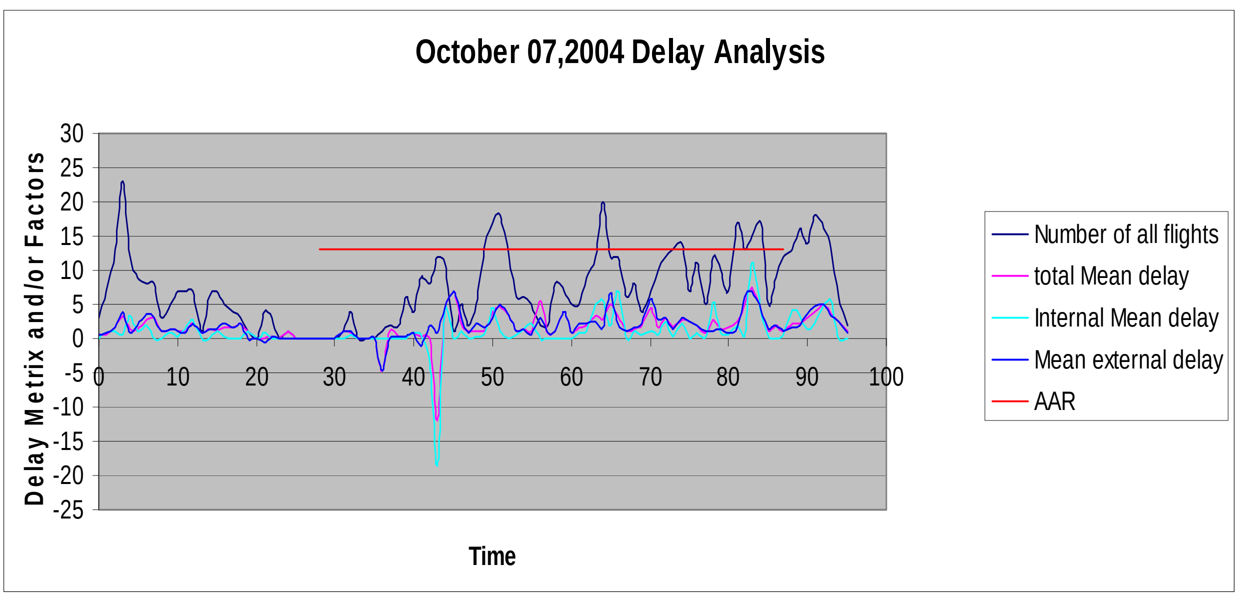


Figure 21. Overall Delay Analysis (October 07, 2004 flights)

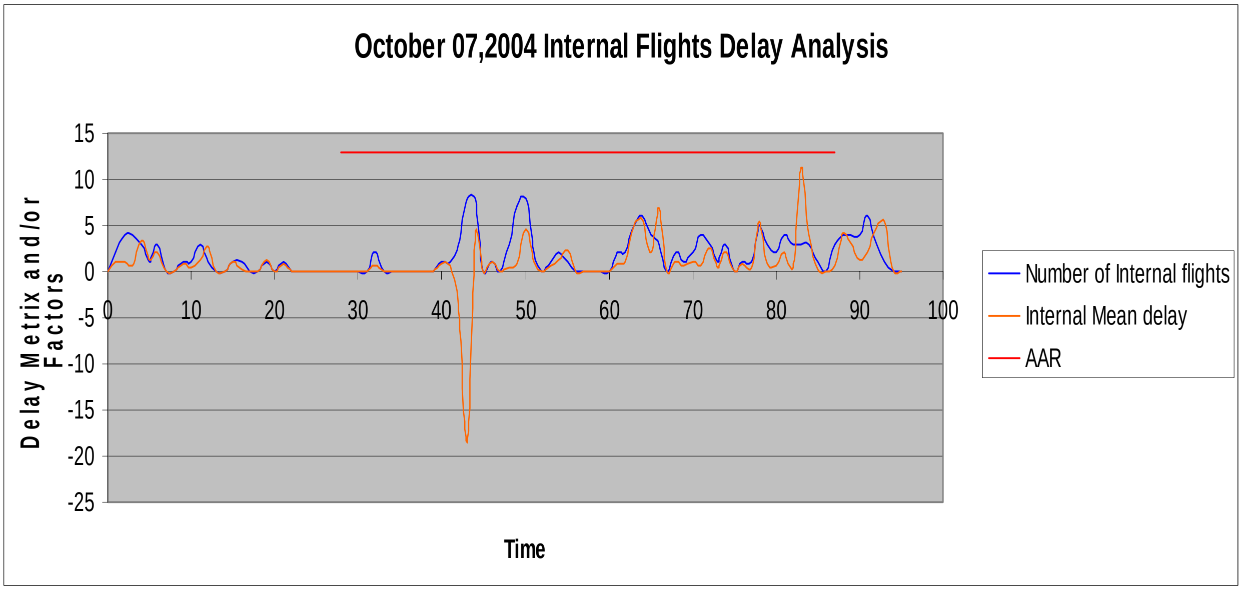


Figure 22. Delay Analysis (October 07, 2004 Internal flights)

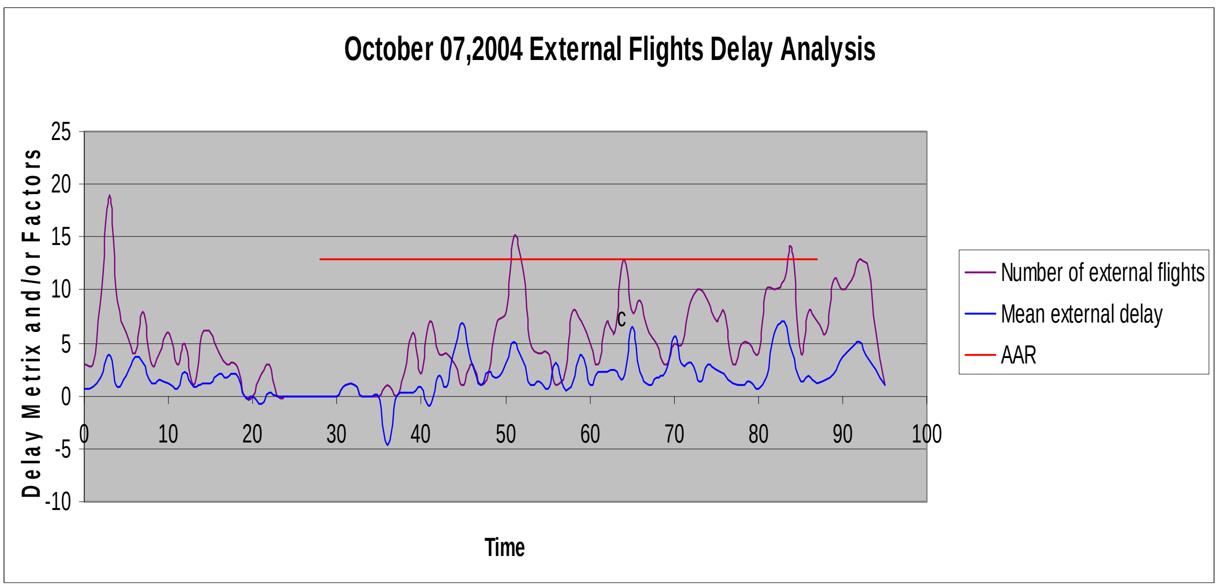


Figure 23. Delay Analysis (October 07, 2004 external flights)

In all, the mean delay time for internal flights is significantly smaller than that of external flights."

On the other hand, Figure 24 was drawn based on the average of data from each day of October 04 to October 10 averaged in 15 minutes intervals. This weekly graph is very similar to daily graphs with high arrival rates early in the morning and after noon. As it is clearly seen from all the graphs including the weekly graph (Figure 22), the trend of arrival volume and delay is almost the same for every sample day of the week and also for the average of weekly data. Arrival volume and delay are high from around 12:00 am to around 6:00 am and then from 10:00 am to 11:59 pm. With up and downs on the graph, arrival rate seems to have a sinusoidal flow with time. From 6:00 am to 10:00am appears to be the slowest time of the day for every sample day. It has been observed that delays occur around the same time of the day.

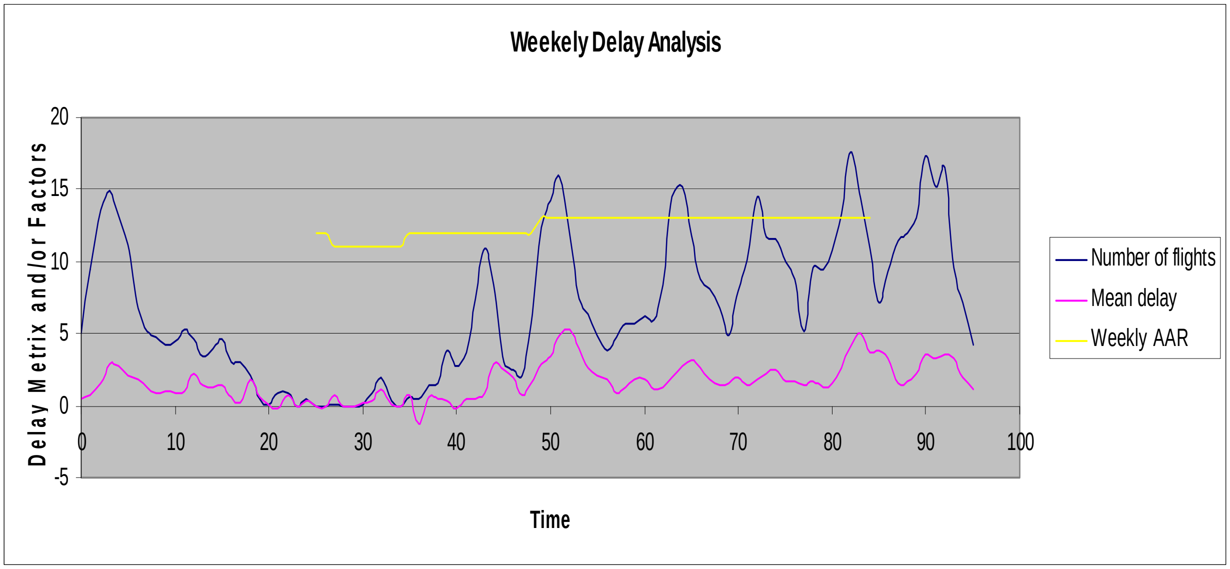


Figure 24. Delay Analysis (Weekly Graph: October 04,2004 - October 10,2004)

3. Results and Conclusions

- Arrival delays have the same pattern every day and are direct result of higher arrival demand.
- Even though delays occur while demand is less than AAR, big arrival delays occur mostly when arrival demand exceeds AAR.
- Average arrival delay for the first week of October was 1.633 min/aircraft. This number does not include terminal delay. Nor does it include taxi-in delay.
- The AAR set for the 15 minute interval does not necessarily indicate the maximum arrival capacity for that specific period.
- Arrival delays for external flights are consistently more than that of internal flights by a minimum of 10% and a maximum of 89% with daily average of 31%.

C. Meter Fix Flight Time Analysis

1. Background

As stated before, Traffic Management Advisor (TMA) is an air traffic control automation system that is in use in 7 Air Route Traffic Control Centers (ARTCC) to enable time based metering (spacing) to busy airports within their air space. The goal of TMA is to improve the flow of arrival traffics to Terminal Radar Approach Control (TRACON) airspace at major airports. It will also assist controllers in sequencing and scheduling arrivals into airports, as well as assign landing slots to aircrafts.

The aim of this analysis can be divided into two parts:

A) To provide data concerning all flights coming from departure airports and arriving at the Philadelphia airport.

B) To provide data concerning all flights coming from departure airports and arriving at the specific meter fixes, namely BUNTS and Cedar Lake (VCN). See Figure 25 for major meter fixes to PHL.

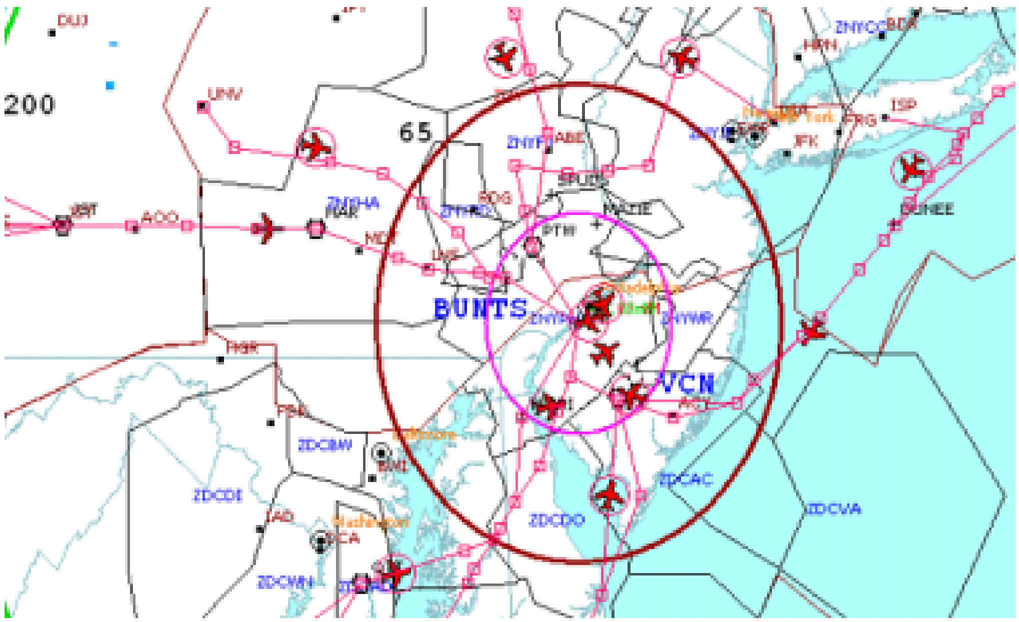


Figure 25. Arrival Traffic Flow through Major Meter Fixes

The log-file data generated by Flight Explorer was used to calculate the time it took a flight to fly from one arc radius to another, or from the 200 nmi arc to a specific meter fix. With the flight times determined from the log-file data, an informed decision can be made on where delays occur more frequently, at what periods of the day delays occur, when there is going to be a rush, and more importantly, and how we can reduce the fuel cost of flights.

2. Meter Fix Analysis using Flight Explorer

Flight Explorer is an Internet based application that monitors flights in the U.S National Airspace System. It records the time a flight leaves the departure airport and the time it arrives at the arrival airport. It also records the estimated time and scheduled time of arrival for each flight. Flight Explorer also shows flight history and flight route plan, the type of aircraft and the speed, latitude and longitude of each flight, among other features. It also shows the time a flight enters area, nears destination, and arrives at a runway.

In Flight Explorer, three elliptical rings in radius of 200nmi, 65nmi, and 26nmi were created around the Philadelphia airport to help gather data for internal and external flights. All flights originated inside the 200nmi ring represented internal flights, while flights originated outside the 200nmi ring represented external flights.

The list of airports were added in the Flight Explorer memory so that it would only show and remember the names of the airports that have been selected, rather than showing the names of all airports in the United States. With the 200nmi arc representing the boundary separating internal and external flights, the 65nmi arc was designated “entered area” arc because it was necessary to have an arc that will not include too many airports within it. That is, it was required that the majority of the airports within the 200nmi radius would contain flights going into the “entered area” arc, while the 26nmi radius arc would be the “near destination” arc. Since one of the goals was to obtain some readings from the following major airports: JFK, EWR, and LGA, the 65nmi arc was created so that they are located just outside the 65nmi radius. The 26nmi arc was created to mark the location of BUNTS and PTW (Pottstown) meter fixes to PHL, that cover most flights (about 60%) arriving at PHL. The other gates include SPUDS, ODESA, Cedar Lake (VCN), MAZIE, SLATT, Johnstown (JST), and TERRY.

The flights that pass through BUNTS are primarily turbojet aircrafts from the Midwest and West coast. Another third of PHL traffic is a mix of jets and props that arrive from the South and East over TERRY and Cedar Lake (VCN) respectively. TERRY captures traffic from Atlanta, Memphis and the Gulf states; Cedar Lake is the entry point for flights originating on the Atlantic Coast, that is, from Boston to Miami; MAZIE is the entry point for jets from upstate New York and parts of New England. However, prop traffic from those areas is routed over PTW.

3. Data Analysis for Internal Flights

Flight Explorer was set to provide daily data for all internal flights arriving at PHL. When this data was received, it was transferred to an excel worksheet so that work could be done on it. While in excel, the data was sorted according to aircraft arrived, aircraft near destination, and aircraft entered area in ascending order.

When this was done, the data was sorted again in terms of aircraft id in ascending order, so that each flight would be arranged in order, for example, "AA 25 arrived," "AA25 near destination," and "AA25 entered area." At this stage, a programmed filter was applied that extracted internal flights from the log-file. In the excel worksheet, the programmed filters occupied three columns because in excel, each cell is not allowed to have more than seven arguments. Also, since the focus was on airports that have flights passing through the BUNTS and PTW meter fix, there was no need to make use of all the 42 airports in the argument.

In the log-file data presented in Table II, it was noted that some flights were missing either the entered area, near destination, or arrival time. This was due to the fact that flights that missed either one of the three items mentioned above were taken into account in the earlier plots, and so when studying the graphs, there was a noticeable jump in time of some flights. For example, flight AA09 might be missing entered area time, and so in the plot for entered area to near destination, flight AA09 will be missing. While in the near destination to arrival plot, flight AA09 will be there. And so, to make the plots more readable and understandable, any flight that missed any one of the three items that was mentioned above was deleted. For instance, in Table II, looking at the last column, the rows that contain “Empty” would be the rows that would be deleted.

After calculating the time differences between entered area-to-near destination (EA-ND), and near destination-to-arrival (ND-ARR), calculation of the mean and standard deviation for EA-ND, and ND-ARR followed next. When calculation of the mean and standard deviation was completed, it was time to plot the graphs.

Table II. Log-file Data for Nov. 11, 2004

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	T	U
										Filters	Filters	Filters	serial #	hr-to-min	min	sec-to-mi	total	EA-ND	ND-Arr
11:54:20	1003	Aircraft arrived	ALO3822	MDT/PH	MDT	PHL		11:25	11:53	MDT	NO	NO	0.496065	660	54	0.33	714.33	7.83	8.38
11:38:07	1010	Aircraft entered area	ALO3822	65nm	MDT	PHL	DH8A	11:25	11:44	MDT	NO	NO	0.484803	660	38	0.12	698.12		
11:45:57	1009	Aircraft near destination	ALO3822	MDT/PH	MDT	PHL	DH8A	11:25	11:44	MDT	NO	NO	0.490243	660	45	0.95	705.95		
02:03:10	1003	Aircraft arrived	ALO3851	ELM/PHI	ELM	PHL	DH8A	01:11	02:02	ELM	NO	NO	0.085532	120	3	0.17	123.17	9.68	11.8
01:41:41	1010	Aircraft entered area	ALO3851	65nm	ELM	PHL	DH8A	01:11	02:00	ELM	NO	NO	0.070613	60	41	0.68	101.68		
01:51:22	1009	Aircraft near destination	ALO3851	ELM/PHI	ELM	PHL	DH8A	01:11	02:00	ELM	NO	NO	0.077338	60	51	0.37	111.37		
12:05:04	1003	Aircraft arrived	ALO3890	IPT/PHL	IPT	PHL	DH8A	11:22	12:04	IPT	NO	NO	0.503519	720	5	0.07	725.07	12.05	9.4
11:43:37	1010	Aircraft entered area	ALO3890	65nm	IPT	PHL	DH8A	11:22	11:57	IPT	NO	NO	0.488623	660	43	0.62	703.62		
11:55:40	1009	Aircraft near destination	ALO3890	IPT/PHL	IPT	PHL	DH8A	11:22	11:57	IPT	NO	NO	0.496991	660	55	0.67	715.67		
11:24:27	1003	Aircraft arrived	ASH2717	ABE/PHI	ABE	PHL	E145	11:06	11:24	NO	ABE	NO	0.475313	660	24	0.45	684.45	6.17	5.17
11:13:07	1010	Aircraft entered area	ASH2717	65nm	ABE	PHL	E145	11:06	11:25	NO	ABE	NO	0.467442	660	13	0.12	673.12		
11:19:17	1009	Aircraft near destination	ASH2717	ABE/PHI	ABE	PHL	E145	11:06	11:25	NO	ABE	NO	0.471725	660	19	0.28	679.28		
01:39:00	1003	Aircraft arrived	ASH2778	AVP/PHI	AVP	PHL	CRJ2	01:09	01:38	AVP	NO	NO	0.06875	60	39	0	99	7.18	9.32
01:22:30	1010	Aircraft entered area	ASH2778	65nm	AVP	PHL	CRJ2	01:09	01:37	AVP	NO	NO	0.057292	60	22	0.5	82.5		
01:29:41	1009	Aircraft near destination	ASH2778	AVP/PHI	AVP	PHL	CRJ2	01:09	01:37	AVP	NO	NO	0.06228	60	29	0.68	89.68		
11:47:37	1003	Aircraft arrived	ASH2799	AVP/PHI	AVP	PHL	CRJ2	11:19	11:47	AVP	NO	NO	0.4914	660	47	0.62	707.62	8.83	5.83
11:32:57	1010	Aircraft entered area	ASH2799	65nm	AVP	PHL	CRJ2	11:19	11:46	AVP	NO	NO	0.481215	660	32	0.95	692.95		
11:41:47	1009	Aircraft near destination	ASH2799	AVP/PHI	AVP	PHL	CRJ2	11:19	11:46	AVP	NO	NO	0.48735	660	41	0.78	701.78		
01:59:10	1003	Aircraft arrived	BTA3421	EWR/PH	EWR	PHL	E135	01:25	01:58	NO	NO	EWR	0.082755	60	59	0.17	119.17	14.5	10.82
01:33:51	1010	Aircraft entered area	BTA3421	65nm	EWR	PHL	E135	01:25	01:48	NO	NO	EWR	0.065174	60	33	0.85	93.85		
01:48:21	1009	Aircraft near destination	BTA3421	EWR/PH	EWR	PHL	E135	01:25	01:48	NO	NO	EWR	0.075243	60	48	0.35	108.35		
12:34:34	1010	Aircraft entered area	CHQ3217	65nm	LGA	PHL	E145	12:10	12:46	NO	NO	LGA	0.524005	720	34	0.57	754.57	2.67	Empty
12:37:14	1009	Aircraft near destination	CHQ3217	LGA/PHL	LGA	PHL	E145	12:10	12:47	NO	NO	LGA	0.525856	720	37	0.23	757.23		
02:34:04	1003	Aircraft arrived	CHQ3222	LGA/PHL	LGA	PHL	E145	01:59	02:33	NO	NO	LGA	0.106991	120	34	0.07	154.07	4.52	7.83
02:21:43	1010	Aircraft entered area	CHQ3222	65nm	LGA	PHL	E145	01:59	02:34	NO	NO	LGA	0.098414	120	21	0.72	141.72		
02:26:14	1009	Aircraft near destination	CHQ3222	LGA/PHL	LGA	PHL	E145	01:59	02:34	NO	NO	LGA	0.101551	120	26	0.23	146.23		
05:52:00	1003	Aircraft arrived	EPS105	UCA/PHI	UCA	PHL	MU2	05:06	05:51	NO	NO	UCA	0.244444	300	52	0	352	7.22	4.27
05:40:31	1010	Aircraft entered area	EPS105	65nm	UCA	PHL	MU2	05:06	05:58	NO	NO	UCA	0.23647	300	40	0.52	340.52	7.98	Empty
08:47:16	1010	Aircraft entered area	EPS105	65nm	UCA	PHL	MU2	08:13	09:03	NO	NO	UCA	0.366157	480	47	0.27	527.27		
05:47:44	1009	Aircraft near destination	EPS105	UCA/PHI	UCA	PHL	MU2	05:06	05:58	NO	NO	UCA	0.241481	300	47	0.73	347.73		
08:55:15	1009	Aircraft near destination	EPS105	UCA/PHI	UCA	PHL	MU2	08:13	09:03	NO	NO	UCA	0.371701	480	55	0.25	535.25		
01:38:11	1003	Aircraft arrived	JIA2301	SYR/PHL	SYR	PHL	CRJ2	00:51	01:32	NO	NO	SYR	0.068183	60	38	0.18	98.18	7	11.83
01:19:21	1010	Aircraft entered area	JIA2301	65nm	SYR	PHL	CRJ2	00:51	01:32	NO	NO	SYR	0.055104	60	19	0.35	79.35		
01:26:21	1009	Aircraft near destination	JIA2301	SYR/PHL	SYR	PHL	CRJ2	00:51	01:32	NO	NO	SYR	0.059965	60	26	0.35	86.35		
02:23:37	1003	Aircraft arrived	PDT4169	SWF/PHI	SWF	PHL	DH8B	01:29	02:23	NO	NO	SWF	0.099734	120	23	0.62	143.62	10	15.93
01:57:41	1010	Aircraft entered area	PDT4169	65nm	SWF	PHL	DH8B	01:29	02:19	NO	NO	SWF	0.081725	60	57	0.68	117.68		
02:07:41	1009	Aircraft near destination	PDT4169	SWF/PHI	SWF	PHL	DH8B	01:29	02:19	NO	NO	SWF	0.088669	120	7	0.68	127.68		
01:21:31	1003	Aircraft arrived	PDT4172	BGM/PH	BGM	PHL	DH8B	00:43	01:21	NO	BGM	NO	0.056609	60	21	0.52	81.52	6.83	6.33

The first plot (Figure 26) is the EA-ND graph where the Y- axis is the time difference between entered area and near destination, and the X- axis is the log-time for entered area in ascending order. The second plot (Figure 27) is the ND-ARR graph where the Y-axis is the time difference between near destination and arrival time, and the X-axis is the log-time for near destination.

The plots of Figure 26 and Figure 27 are for the analysis of November 11th, 2004. The plots show that on this day, there were few flights that arrived at PHL. The reason could be attributed to bad weather (i.e., heavy rain all day) on that day. Also, looking at Figure 226 and Figure 27, it showed that sometimes it took more time to go from ND-ARR, compared to the time to go from EA-ND.

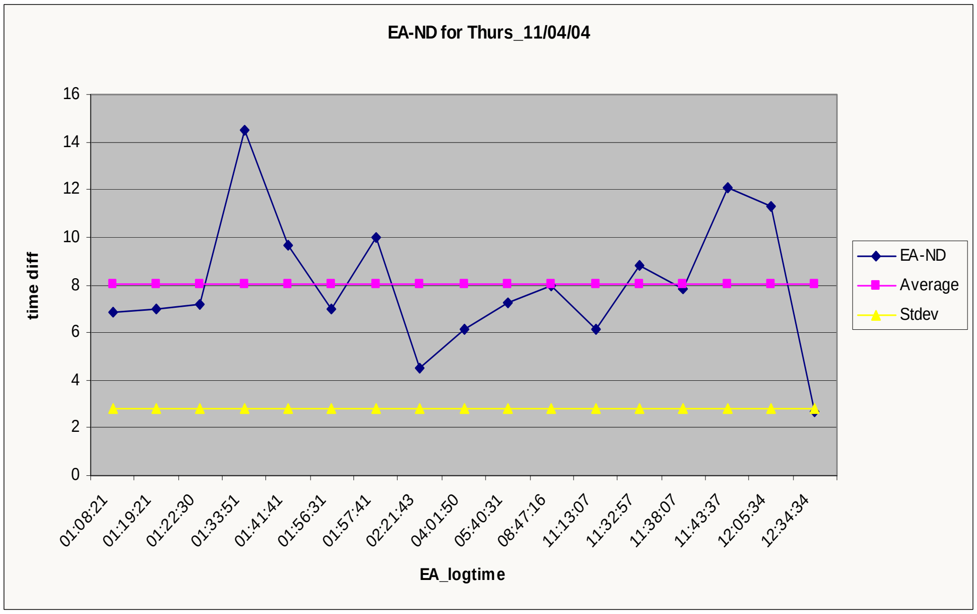


Figure 26. The Graph of EA-ND

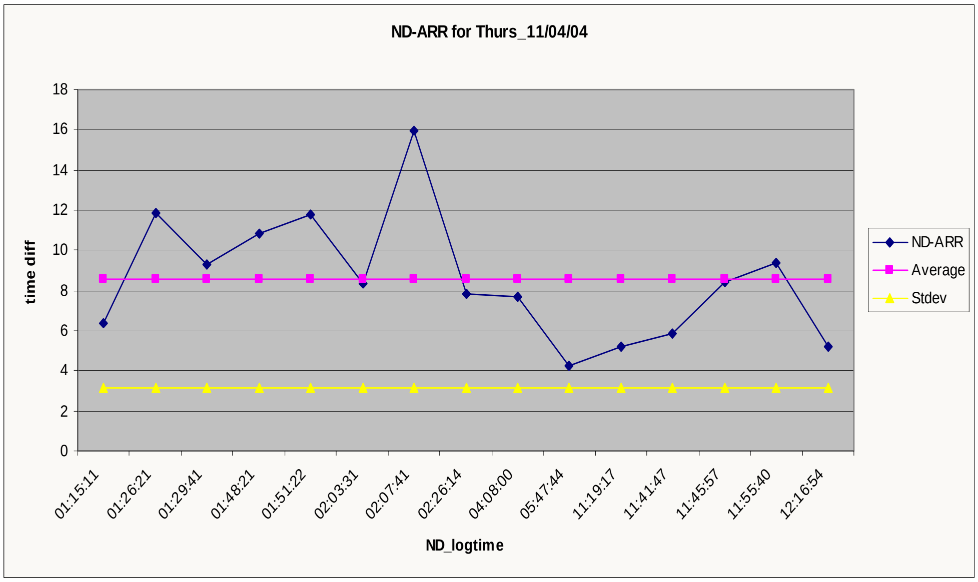


Figure 27. The graph of ND-ARR

4. Data Analysis for External Flights

The process for collecting data for the external flights was equally the same as that of the internal flights, except this time, the focus was on flights originating outside of the 200nmi radius. Since the focus was on flights that originated outside of the 200nmi arc to a meter fix, the settings on the Flight Explorer were changed accordingly. An example extraction of the data from days of the week intended to analyze is shown in Table III.

Table III: Sample of Raw Data File from Flight Explorer

	A	B	C	D	E	F	G	H	I	J	K
1	11/11/2004	00:00:07	1010	Aircraft entered area	USA1126	PHL200	CLT	PHL	B762	23:25	00:34
2	11/11/2004	00:00:18	1009	Aircraft near destination	CHQ3031	STL/PHL 22:09/00:07	STL	PHL	E145	22:09	00:07
3	11/11/2004	00:00:28	1003	Aircraft arrived	JIA2292	PHF/PHL 23:12/23:5	PHF	PHL	CRJ2	23:12	23:58
4	11/11/2004	00:00:39	1007	Aircraft flight plan changed	USA441	PVD/PHL 23:19/00:1	PVD	PHL	B752	23:19	00:12
5	11/11/2004	00:00:39	1006	Aircraft ETA changed	USA441	from 00:08 to 00:12	PVD	PHL	B752	23:19	00:12
6	11/11/2004	00:00:49	1007	Aircraft flight plan changed	BAW69	EGLL/KPHL 17:10/00	EGLL	KPHL	B772	17:10	00:22
7	11/11/2004	00:00:49	1006	Aircraft ETA changed	BAW69	from 00:24 to 00:22	EGLL	KPHL	B772	17:10	00:22
8	11/11/2004	00:00:50	1003	Aircraft arrived	USA826	PHX/PHL 19:48/23:5	PHX	PHL	A319	19:48	23:56
9	11/11/2004	00:01:00	1007	Aircraft flight plan changed	AAL1242	ORD/PHL 23:43/01:1	ORD	PHL	MD82	23:43	01:17
10	11/11/2004	00:01:00	1006	Aircraft ETA changed	AAL1242	from 01:16 to 01:17	ORD	PHL	MD82	23:43	01:17
11	11/11/2004	00:01:01	1003	Aircraft arrived	USA723	BOS/PHL 22:57/23:5	BOS	PHL	A321	22:57	23:57
12	11/11/2004	00:01:33	1007	Aircraft flight plan changed	AAL1242	ORD/PHL 23:43/01:1	ORD	PHL	MD82	23:43	01:15
13	11/11/2004	00:01:33	1006	Aircraft ETA changed	AAL1242	from 01:17 to 01:15	ORD	PHL	MD82	23:43	01:15
14	11/11/2004	00:01:34	1007	Aircraft flight plan changed	USA435	FLL/PHL 21:54/00:1	FLL	PHL	B752	21:54	00:18
15	11/11/2004	00:01:34	1006	Aircraft ETA changed	USA435	from 00:15 to 00:18	FLL	PHL	B752	21:54	00:18
16	11/11/2004	00:02:03	1009	Aircraft near destination	UAL952	ORD/PHL 22:37/00:1	ORD	PHL	B733	22:37	00:11
17	11/11/2004	00:02:23	1003	Aircraft arrived	ASH2612	BGR/PHL 22:39/00:0	BGR	PHL	CRJ2	22:39	00:03
18	11/11/2004	00:02:53	1007	Aircraft flight plan changed	AAL1896	DFW/PHL 21:38/00:1	DFW	PHL	MD82	21:38	00:17
19	11/11/2004	00:02:53	1006	Aircraft ETA changed	AAL1896	from 00:21 to 00:17	DFW	PHL	MD82	21:38	00:17
20	11/11/2004	00:03:23	1009	Aircraft near destination	TRS784	MCO/PHL 22:03/00:1	MCO	PHL	B712	22:03	00:10
21	11/11/2004	00:03:53	1006	Aircraft ETA changed	CHQ5775	from 00:47 to 00:44	STL	PHL	E145	22:55	00:44
22	11/11/2004	00:04:13	1007	Aircraft flight plan changed	TRS782	MCO/PHL 00:01/02:1	MCO	PHL	B712	00:01	02:12
23	11/11/2004	00:04:13	1006	Aircraft ETA changed	TRS782	from 02:19 to 02:12	MCO	PHL	B712	00:01	02:12
24	11/11/2004	00:04:23	1010	Aircraft entered area	N424RA	PHL200	CPS	PHL	BE20	22:11	00:53
25	11/11/2004	00:04:33	1007	Aircraft flight plan changed	USA654	TNCA/KPHL 21:04/0	TNCA	KPHL	B752	21:04	01:12
26	11/11/2004	00:04:33	1006	Aircraft ETA changed	USA654	from 01:11 to 01:12	TNCA	KPHL	B752	21:04	01:12
27	11/11/2004	00:04:33	1007	Aircraft flight plan changed	AWE256	PHX/PHL 23:42/03:4	PHX	PHL	A319	23:42	03:40
28	11/11/2004	00:04:33	1006	Aircraft ETA changed	AWE256	from 03:30 to 03:40	PHX	PHL	A319	23:42	03:40
29	11/11/2004	00:04:43	1003	Aircraft arrived	ALO3746	MDT/PHL 23:35/23:5	MDT	PHL	DH8A	23:35	23:56
30	11/11/2004	00:04:43	1003	Aircraft arrived	ASH2980	CLE/PHL 22:56/23:5	CLE	PHL	E145	22:56	23:57

Out of all the event categories in the flight alert system, “Aircraft entered area” and “Aircraft near destination” events were needed; hence all other entries were sorted out from the log-file. For example, Table III was sorted to become Table IV.

Table IV: Sample of Sorted File from Flight Explorer

	A	B	C	D	E	F	G	H	I	J
1	**index**	**date**	**event_code**	**event_name**	**aircraft_id**	**detail_info**	**origin**	**destination**	**depart_time**	**time**
2	849	10/13/2004	1010	Aircraft entered area	AAL1146	PHL200	ORD	PHL	17:12:00	18:48:00
3	875	10/13/2004	1009	Aircraft near destination	AAL1146	ORD/PHL 17:12/18:47	ORD	PHL	17:12:00	18:47:00
4	715	10/13/2004	1010	Aircraft entered area	AAL1248	PHL200	ORD	PHL	12:51:00	14:30:00
5	723	10/13/2004	1009	Aircraft near destination	AAL1248	ORD/PHL 12:51/14:28	ORD	PHL	12:51:00	14:28:00
6	926	10/13/2004	1010	Aircraft entered area	AAL1374	PHL200	ORD	PHL	19:16:00	20:53:00
7	960	10/13/2004	1009	Aircraft near destination	AAL1374	ORD/PHL 19:16/20:54	ORD	PHL	19:16:00	20:54:00
8	790	10/13/2004	1010	Aircraft entered area	AAL1430	PHL200	ORD	PHL	15:28:00	17:04:00
9	799	10/13/2004	1009	Aircraft near destination	AAL1430	ORD/PHL 15:28/17:03	ORD	PHL	15:28:00	17:03:00
10	543	10/13/2004	1010	Aircraft entered area	AAL1588	PHL200	ORD	PHL	3:03:00	4:37:00
11	552	10/13/2004	1009	Aircraft near destination	AAL1588	ORD/PHL 03:03/04:37	ORD	PHL	3:03:00	4:37:00
12	673	10/13/2004	1010	Aircraft entered area	AAL1856	PHL200	ORD	PHL	11:31:00	13:06:00
13	695	10/13/2004	1009	Aircraft near destination	AAL1856	ORD/PHL 11:31/13:03	ORD	PHL	11:31:00	13:03:00
14	494	10/13/2004	1010	Aircraft entered area	AAL2082	PHL200	ORD	PHL	1:14:00	2:51:00
15	505	10/13/2004	1009	Aircraft near destination	AAL2082	ORD/PHL 01:14/02:42	ORD	PHL	1:14:00	2:42:00
16	1033	10/13/2004	1010	Aircraft entered area	AAL540	PHL200	ORD	PHL	21:34:00	23:10:00
17	1061	10/13/2004	1009	Aircraft near destination	AAL540	ORD/PHL 21:34/23:11	ORD	PHL	21:34:00	23:11:00
18	1031	10/13/2004	1010	Aircraft entered area	ALO3746	PHL200	MDT	PHL	22:28:00	22:49:00
19	1044	10/13/2004	1009	Aircraft near destination	ALO3746	MDT/PHL 22:28/22:49	MDT	PHL	22:28:00	22:49:00
20	919	10/13/2004	1010	Aircraft entered area	ALO3802	PHL200	MDT	PHL	20:04:00	20:25:00
21	936	10/13/2004	1009	Aircraft near destination	ALO3802	MDT/PHL 20:04/20:25	MDT	PHL	20:04:00	20:25:00
22	612	10/13/2004	1010	Aircraft entered area	ALO3822	PHL200	MDT	PHL	10:19:00	10:38:00
23	619	10/13/2004	1009	Aircraft near destination	ALO3822	MDT/PHL 10:19/10:38	MDT	PHL	10:19:00	10:38:00
24	657	10/13/2004	1010	Aircraft entered area	ALO3840	PHL200	MDT	PHL	12:06:00	12:30:00
25	669	10/13/2004	1009	Aircraft near destination	ALO3840	MDT/PHL 12:06/12:30	MDT	PHL	12:06:00	12:30:00
26	810	10/13/2004	1010	Aircraft entered area	ALO3841	PHL200	UNV	PHL	17:12:00	18:02:00
27	830	10/13/2004	1009	Aircraft near destination	ALO3841	UNV/PHL 17:12/18:02	UNV	PHL	17:12:00	18:02:00
28	738	10/13/2004	1010	Aircraft entered area	ALO3887	PHL200	ROC	PHL	14:47:00	15:55:00
29	762	10/13/2004	1009	Aircraft near destination	ALO3887	ROC/PHL 14:47/15:58	ROC	PHL	14:47:00	15:58:00

By running a program routine, the mean time differences between “Aircraft entered area” and “Aircraft near destination” events were obtained, which is the time it took for a plane to fly from 200 nmi radius to a meter a fix.

5. Statistics for BUNTS Meter Fix

Starting the first week of November, the near destination nautical mile radius ellipse was re-adjusted to just cut across the BUNTS meter fix which was 26.46nm from Philadelphia airport, while retaining the 200 nautical mile radius ellipse. Readings were collected for the 1st, 2nd, 3rd and 4th of November. From the 195 flights that passed through the BUNTS meter fix on the 1st of November, the mean flight time of 23.692 minutes was calculated with a standard deviation of 3.403 as shown in Figure 28.

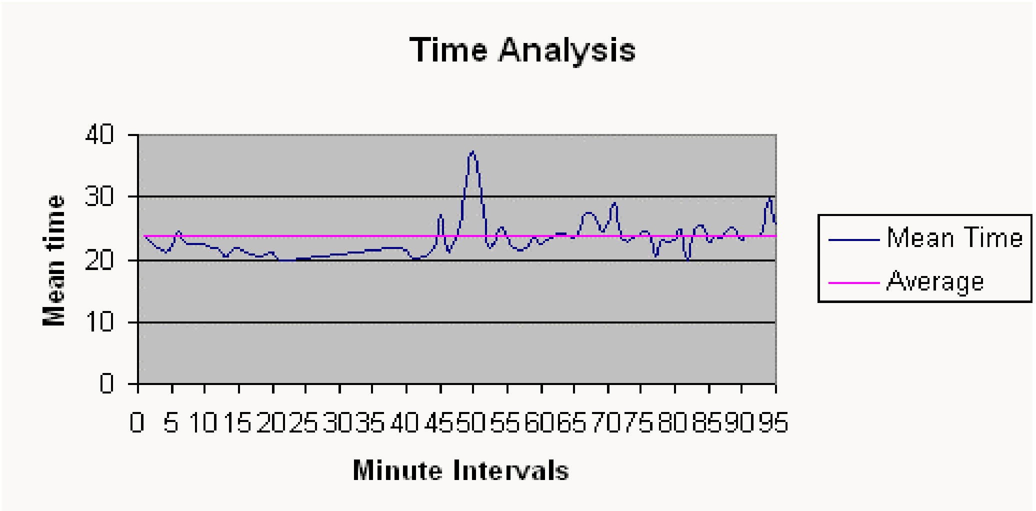


Figure 28. Mean Flight Time at Fifteen Minute Time Interval

Also, from the 89 flights that passed through the BUNTS meter fix on the 2nd of November, a mean flight time of 24.244 minutes with a standard deviation of 4.187 was calculated as shown in Figure 29.

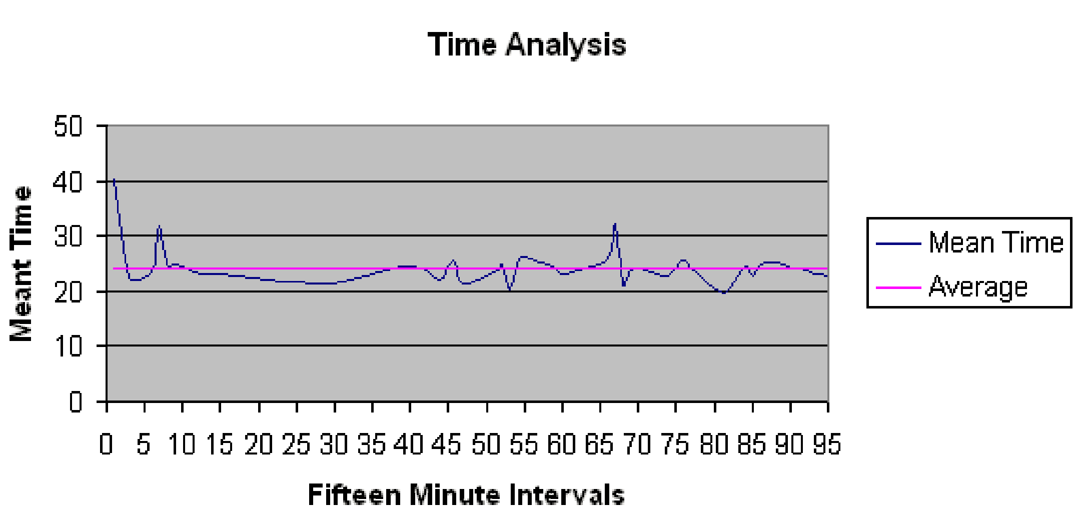


Figure 29. Mean Time at Fifteen Minute Time Interval

From the 220 flights that passed through the BUNTS meter fix on the 3rd of November, a mean flight time of 24.1151 minutes with a standard deviation of 4.394 was calculated as well. And out of 154 flights that passed through the BUNTS meter fix on the 4th of November, a mean flight time of 24.234 minutes with a standard deviation of 4.829 was obtained.

6. Statistics for VCN Meter Fix

For the second week of November, the "near destination" nautical mile radius ellipse was readjusted again to cut across the VCN meter fix which is about 23nmi from the Philadelphia airport, while retaining the 200 nautical mile radius ellipse. Data was collected for the 8th through the 12th of November. From the112 flights that passed through the VCN meter fix on the 8th of November, a mean flight time of 34.35 minutes with a standard deviation of 7.815 were calculated. It was observed that these values were reasonably close to the values recorded during the month of October. For the 9th of November, a mean flight time of 35.87 minutes with a standard deviation of 6.44 was calculated from the 50 flights. For the 10th of November, a mean flight time of 34.812 minutes and a standard deviation of 5.31 were calculated from a fleet of 104 flights as shown in Figure 30.

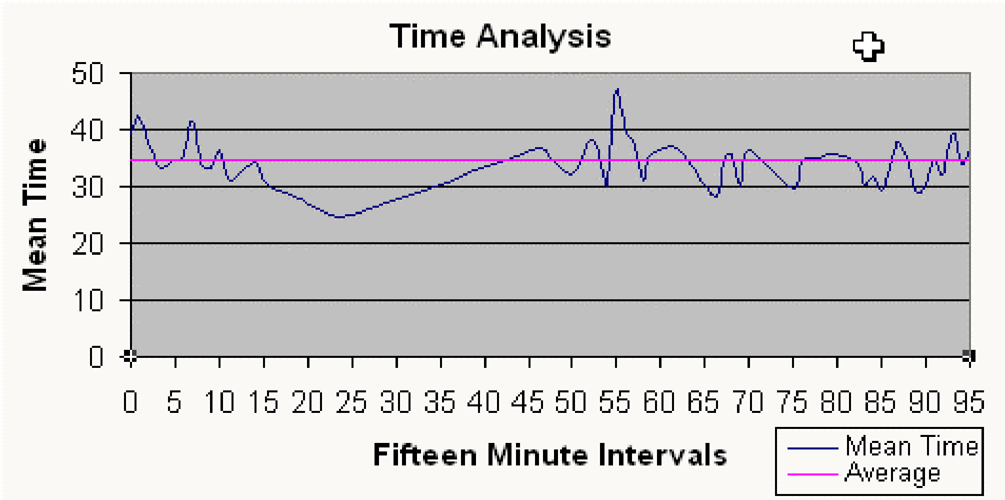


Figure 30. Mean Time at Fifteen Minutes Time Interval

And for the 12th of November, a mean flight time of 33.643 minutes with a standard deviation of 6.88 out of 91 flights was again evaluated for that day. Also, for the 11th of November, a mean flight time of 32.59 minutes with a standard deviation of 5.85 was calculated out of 92 flights evaluated for that day as shown in Figure 31.

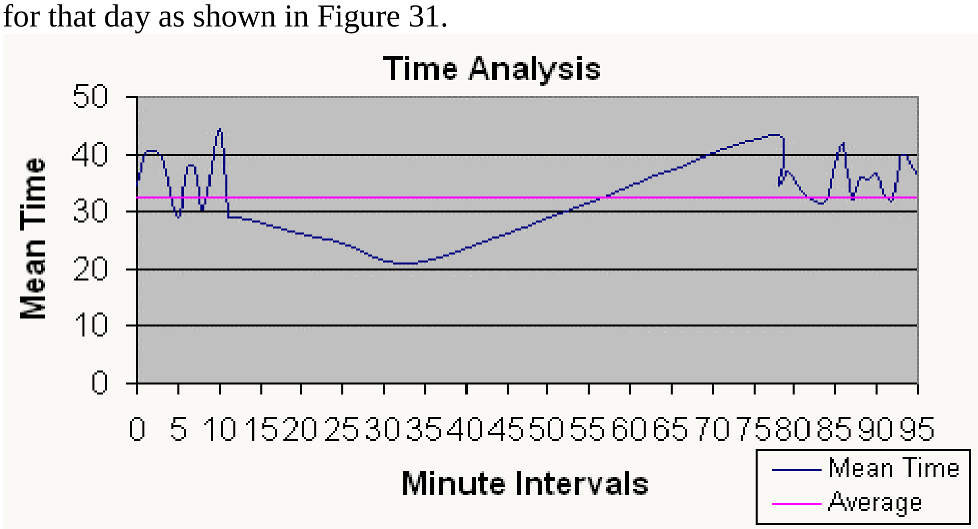


Figure 31. Mean Time at Fifteen Minute Time Interval

7. Relevance to TMA Assessment

The analysis of the time differences between rings could be related to TMA in terms of the delay that occurs between the arcs. It can be used to estimate the mean arrival delay in some ways. It can also be used to estimate where delays occur more frequently, and how much time it takes for the delay. Also, the analysis can be related to TMA in terms of Arrival Utilization. According to ASPM, Arrival Utilization (A_u) assesses how well the Arrival Demand was satisfied for a given time period, taking into account the airport's target arrival capacity in that time period. Airport Performance assesses how well the Arrival Demand was satisfied in all time periods, also taking into account the airport's target arrival capacity as it varied during the day.

Arrival Utilization compares what an airport did to what it could have done. Arrival Utilization are assigned scores of 100 percent when either:

• The target arrival rate is met or
• All the demand is met (regardless of target)

Since both demand and capacity may vary over time, the day was divided into 15 minute time periods and the metric is calculated for each time period. Arrival utilization for a time period is determined by comparing the actual arrivals to the target AAR, or the demand, whichever is less.

$$A_u(t) = \frac{A_l(t)}{\min\{A_d(t), A_r(t)\}}$$

where, $A_l(t)$ is the number of aircraft that landed during a specified time period, $A_d(t)$ is the the number of aircraft that could land within that time period, and $A_r(t)$ is the acceptance rate for the given time *t*.

An example for Arrival Utilization is provided in Figure 32 in which the three components for measuring it are shown in 15 minute intervals.

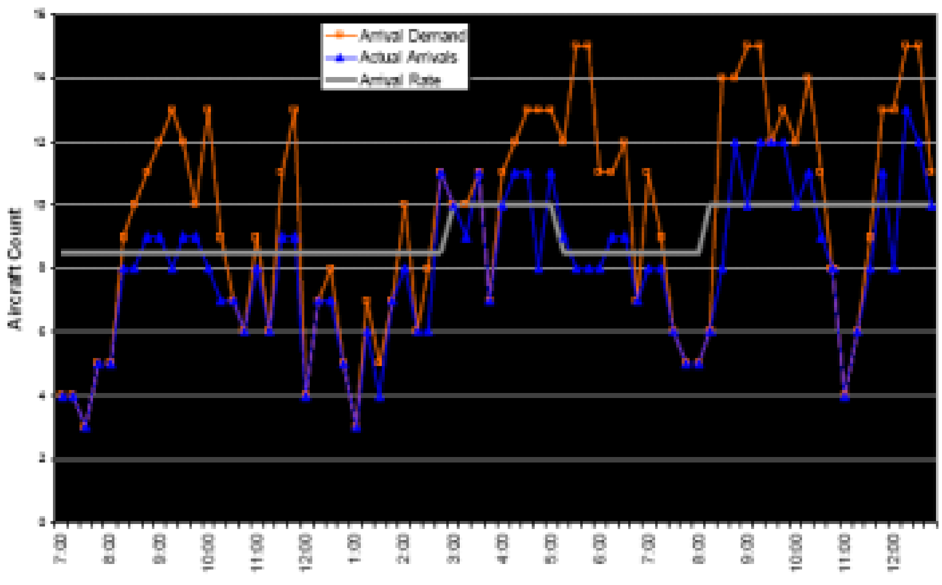


Figure 32. Arrival Utilization Example

8. Other Observations

Most of the traffics going through ODESA are external flights. The percentage of internal flights passing through VCN is only about 20%. A major meter fix that most internal flights pass through is PTW which covers about 95% of internal flights. MAZIE and SPUDS are accepting about 2% of internal flights.

D. Conclusions

This chapter summarizes the works performed for the first several months under the task of FAA integrated metric analysis. The focus of the work reported here is to analyze the baseline status of PHL TRACON, including delay rate and delay time, and flight time interval between meter fixes. One distinctive feature of the analysis presented in the report is that the analysis was performed separately for aircrafts arriving from departure airports located out side of 200nmi radius and those from inside 200 nmi radius. This new approach revealed very interesting statistics and observations that have not been reported or presented before.

The findings are summarized below.

1. Arrival Rate at PHL

- Most arrivals to PHL were between 12:00am to 6:00am and from 10:00am to 11:59am.
- There were more external flights (i.e., outside of the 200nmi radius) arriving to PHL.
- Internal flight arrivals (i.e., inside of the 200nmi radius) to PHL were almost equally distributed between pacing and major airports.
- Externally, more flights originate from pacing airports by a large margin.
- There were other internal (i.e., inside the US) and external (i.e., outside of the U.S) flights arriving into PHL, but they were neither major nor pacing. Observation showed the following:
    - These internal flights originated from U.S civil airports wherein permit covers use by transit military aircrafts
    - These external flights originated from civil government airports, where landing fees and diplomatic clearance may be required.
    - Generally, flights from these civil airports followed the same arrival schedule into PHL.
    -

2. Arrival Delay at PHL

- Arrival delays have the same pattern every day and are direct result of higher arrival demand.
- Even though delays occur while demand is less than AAR, big arrival delays occur mostly when arrival demand exceeds AAR.
- Average arrival delay for the first week of October was 1.633 min/aircraft. This number does not include terminal delay. Nor does it include taxi-in delay.
- Arrival delays for external flights are consistently more than that of internal flights by the amount of minimum 10% and maximum 89% with daily average 31%.

3. Flight Time between Meter Fixes

- Traffic flow through ODESA is mostly of external flight with 40 % of all the external flights.
- Traffic flow through PTW is mostly of internal flight with about 95% of all the internal flights.
- Flights from west pass through BUNTS.
- The number of flights passing through BUNTS is in the range of 90 - 220 a day
- The flight time from the 200nmi arc to BUNTS is in the range of 23 - 25 minutes in average.
- The number of flights passing through VCN is in the range of 80 - 115 a day.
- The flight time from the 200nmi arc to VCN is in the range of 34 - 35 minutes in average

III. TMA Evaluation of Overall Arrival Traffic at IAH

A. Evaluation Method

Not many research works have been done to assess the traffic management advisor's performance at George Bush Intercontinental Airport IAH) [19, 20]. However, the performance of TMA has been evaluated at earlier sites such as Dallas Forth worth (DFW), Denver (DEN), Miami (MIA), Atlanta (ATL), Los Angeles (LAS), Oakland (SFO), and Minneapolis (MSP). The benchmark paper by Harry et al. [4] discussed the performance of TMA in the operational evaluation of thirty-nine rush traffic periods during a one month period in the summer of 1996 at the Fort Worth Air Route Traffic Control Center (ARTCC). Lee et al. [21] discussed about the human factor results obtained from the 1996 TMA operational evaluation. They also investigated TMA usage performance two years later during the 1998 TMA Daily Use Field Survey. Hoang and Swenson [22] described the challenges encountered during the various phases of the TMA field evaluation at the Fort Worth Center (ZFW) in the summer of 1996. Harwood and Sanford [23] assessed Denver Center TMA suitability to determine the extent to which TMA could be used as a decision aid for traffic management tasks. Landry et al. [24] developed operational concepts to assess the Multi-Center Traffic Management Advisor (McTMA) by using arrivals to BOS, overflights and departures to Dulles International Airport (IAD), and overflights and departures to Chicago-O'Hare (ORD). They also described McTMA system architecture and highlighted prospects for near-term deployment to the United States' National Airspace System. In [25], Wong described the principal algorithms and data structures of the Dynamic Planner (DP). He also provided a detailed discussion on the design and operation of the scheduling, sequencing, runway allocation, and miles-in-trail advisor modules of the DP. Farley et al. [26] identified four primary technical challenges of metering in airspace that experienced routine occurrence of airborne holding and in-trail spacing restrictions. Landry et al. [27] discussed about the three tested carried out by NASA engineers to overcome TMA restrictions, such as traffic management within 250 nautical mile radius.

This chapter introduces new performance metrics, for example the distribution distortion index (DDI) that helps to access TMA capability to provide different planning activities such as staffing, distributing traffic load, and changing airport acceptance rate. The other proposed metric, referred to as the Quality of Service (QoS) helps to rate the QoS level of aircraft arrivals during selected peak periods. The current or conventional metrics are deficient in their ability to either predict future traffic load or provide an appreciable rating of arrival traffic performance based on certain QoS levels. This approach applied both the conventional and proposed metrics to aircraft arrival data of IAH during 2003 (pre-TMA) and 2004 (post-TMA). The IAH arrival flight data was obtained from FAA database.

In addition, we developed an arrival traffic model which simulated arrival flights transit via the extreme arc, between the arrival arcs, via the meter fixes, and on the runways at IAH. The arrival arcs are defined as invisible rings which are geographically located around IAH that helps traffic controllers locate the position of arrival aircraft to airport runway. Besides providing flexibility, the simulation would also provide traffic controllers an economical means of safely performing different types of contingency analyses on arriving flights from various departure cities to IAH. The simulation would help traffic controllers predict future traffic flow into IAH local airspace and runway. Lastly, the simulation provided repeatability of arrival pattern of flights to IAH so that various flight traffic activities are recaptured for the purpose of investigation.

Further more, we noticed that the callsign (i.e. combination of airline name and flight number) alone could not identify a unique flight; so, we applied 4 attributes (i.e. callsign, departure city, runway, and month) to uniquely identify flights (UIFs). The FAA referred to frequent flights as those that have at least one weekly arrival in a month. Meanwhile, Trigger flights are groups of UIFS that had greater than or equal to four monthly arrivals at IAH.

B. George Bush Intercontinental Airport (IAH)

Bush Intercontinental (IAH) is located approximately 23 miles north of downtown Houston, near the Sam Houston Toll way (Beltway 8 North). In 1969, IAH Airport became a part of Houston Airport System providing the city of Houston and the entire Gulf Coast region with the very best airport facilities and a wide range of aviation services.

In 2000, IAH was the 8th busiest airport in the US based on total passenger enplanements and the 11th busiest in the world. It was estimated that IAH airport had a regional economic impact of more than $8 billion annually and created more than 90,000 jobs during 2003. Moreover, in 2004, IAH was ranked 2nd among U.S. airports for scheduled non-stop domestic and international destinations, and it increased international destinations by 14 in the first six months of operation. Generally, IAH airport system provides service to 184 destinations (64 being international destinations in 28 countries). Usually, direct services often link IAH with most regions of the country and flights that span the Atlantic and Pacific Oceans. IAH is among OEP 35 airports (Operational Evolutional plan), which are highly recognized as United States' demand impacted airport. Part of OEP 35 initiatives include: increased arrival and departure rates, improved flight during severe en route weather conditions, decreased en route congestion, and improved flight during unfavorable weather conditions.

The present international destinations from IAH include: Africa, Asia, Europe, South America, Europe and Caribbean [17]. IAH served a record number of passengers in 2004 as shown in Table V. The same table provides a statistical analysis of the number of passengers that departed (enplaned) and arrived (deplaned) at IAH from 1999 to 2004. We can see that IAH recorded a greater number of passenger arrivals in 2004 than the previous year (a 6.4% increase). We observed that, in 2004, IAH recorded a 6.44 %, 7.32 %, and 5.1 % increase compared with 2003, 2002, and 2001 respectively.

ZHU is the control center that monitors and guides all aircrafts that traverses the Houston airspace. In June 2003, the FAA deployed the traffic management advisor (TMA) at ZHU to ensure efficient and safe flow of arrival traffic to IAH. Although, partial use of TMA with time based metering (TBM) began in December 2003, the full implementation did not start until June 2004.

George Bush Intercontinental airport system's effort for providing safe and efficient airfield facilities was corroborated, in November 2003, by the opening of a new air carrier runway. The new runway, Runway 8L/26R, is constructed parallel to Runway 8R/26L at about 4,500 feet away. Runway 8L/26R is 9,000 feet long and 150 feet wide with 35 feet shoulders on each side and it includes high-speed exits to the parallel taxiway to ensure speedy flight operations. The new runway is IAH's 5th runway and 3rd parallel Category III runway, permitting triple independent simultaneous all-weather flight operations and it is the 1st runway at IAH which utilizes LED Taxiway Edge Light Fixtures.

Table V. IAH Passenger Departure and Arrival Statistics

George Bush Intercontinental (IAH)						
PASSENGERS' STATUS	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Enplaned (int'l & domestic)	16,464,987	17,521,731	17,437,784	16,897,821	17,003,336	18,254,237
Deplaned (int'l & domestic)	16,586,261	17,729,641	17,365,796	17,007,026	17,148,006	18,251,879
Total (int'l & domestic)	**33,051,248**	**35,251,372**	**34,803,580**	**33,904,847**	**34,151,342**	**36,506,116**

Currently, IAH is one of only three airports in the US that have the ability to land three airplanes at the same time in the lowest visibility conditions. Since the addition of a new runway, the airport has recorded reduced flight delays; reduced airborne traffic jams, especially during bad weather; reduced aircraft ground delays, resulting in lower total emissions and increased capacity of the per hour arrival rate of the airport by 50 percent, allowing the airport to accommodate 96 arrival operations per hour, in low visibility conditions, and 108 arrival operations per hour under normal visibility conditions.

In addition to the construction of a new runway at IAH, the extension of Runway 15R/33L was completed in May 2002. It was extended and widened to 10,000 feet so that it can accommodate arrivals and departures of commercial jets. IAH airfields have been greatly enhanced with new selections of Taxiways which provide efficient movement of aircraft on the ground. Figure 33 shows a pictorial view of IAH runway configuration.

However, when Runway 8L/26R was open, in November 2003, the existing Runway 8R/26L was closed for resurfacing until July 2004. Also, work was carried-out on Runway 9/27 and its Taxiways during the same period as shown in Figure 34. Thus, as a result of all the simultaneous actions we will not be able to properly estimate the impact of TMA time-based metering (TBM) independently with regards to the other changes. Nevertheless, based on the Free Flight Program Office extensive report that TMA is responsible for the overall operational improvement at IAH, we proceeded to analyze the combined effect of these changes in the next chapter.

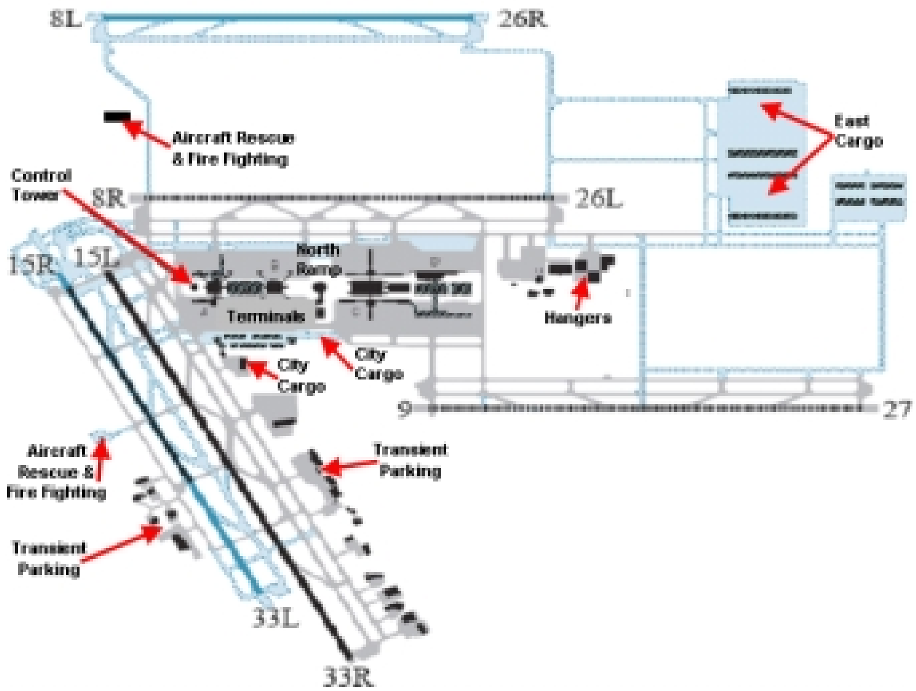


Figure 33. IAH Airport Runway Layouts

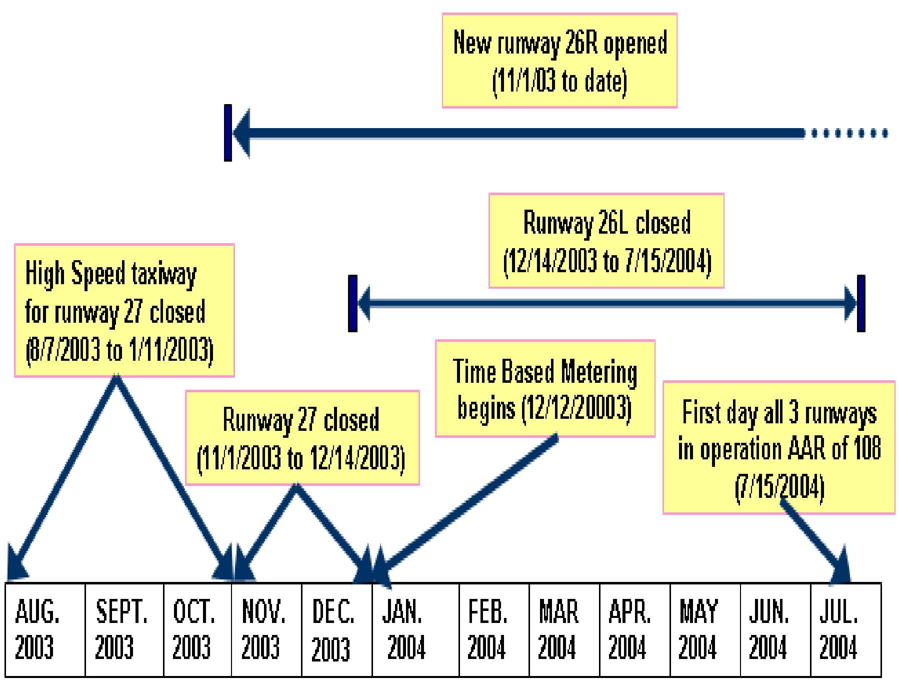


Figure 34. IAH Airport Time Line

C. IAH Arrival Analysis for TMA Evaluation using Conventional Metrics

We evaluated the IAH arrival traffic as a part of TMA operational performance assessment and, as instrumentation variables, we used conventional metrics and a few metrics of our suggestion. We referred to "TMA without TBM (Time based metering)" and "TMA with TBM" periods as "pre-TMA" and "post-TMA" periods, respectively. We conducted the analysis of arrival traffic at IAH to compare the operational performance for pre-TMA duration (January to August 2003) with the post-TMA duration (January to August 2004). The required flight data for the comparison analysis were obtained from the Federal Aviation Administration (FAA) database.

The main problem Traffic Management Coordinators (TMCs) encounter is the phenomenon known as air traffic “rush.” Where rush is defined as a period of time when the number of aircraft destined to the same point exceeds the number that can be accommodated without significant delay or controller and pilot interaction. Figures 35 and 36 show that IAH airport generated a multi-modal distribution for both 2003 and 2004 monthly cumulative airport arrival rate as obtained from the FAA database. TMCs often impose restrictions upon air traffic movement so as to ensure that facility’s capacity is not exceeded during these rush periods. IAH airport typically reports 3 basic rush periods from 5:00 AM to 7:30 AM, 11:00 AM to 2:00 PM, and 3:00 PM to 5:00 PM, which are usually observed on Monday mornings, Thursdays afternoons, Fridays, Saturday Mornings, and Sundays. From the two figures, we observed that IAH airport experiences greater number of arrivals during these rush hour periods.

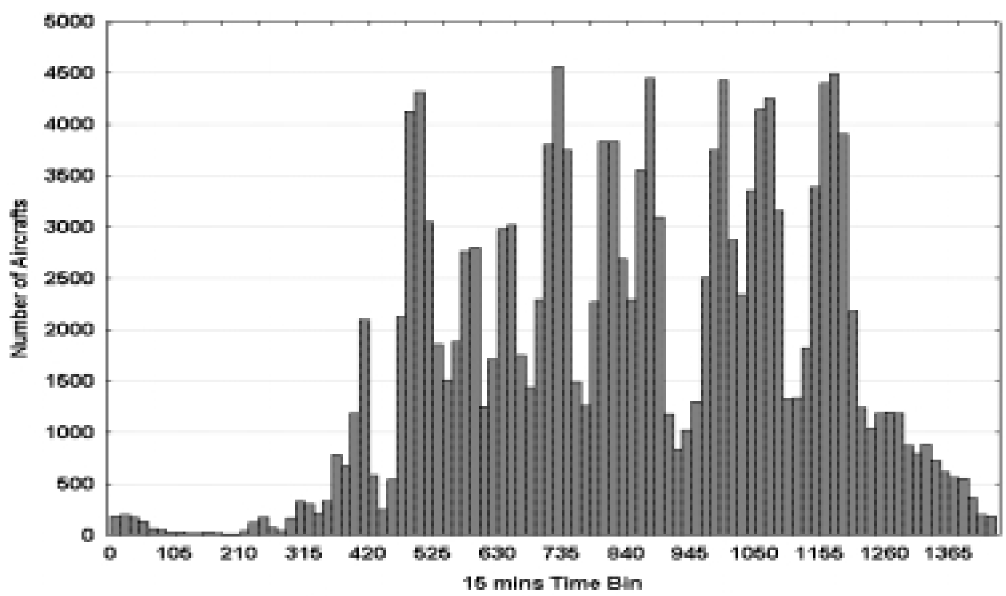


Figure 35. 2003 IAH Airport Daily Cumulative Airport Arrival Rate Distribution

For analysis purpose, we picked three rush periods from the arrival distributions and they are corresponds to, in minute: 1256 to 1356 (**rush hour 1**), 1557 to 1657 (**rush hour 2**), and 1857 to 1957 (**rush hour 3**) Local Time. The 2003 database generated a total of **12,422**, **13,486**, and **16,063** flight arrivals in rush hour 1, 2 and 3, respectively. Meanwhile, the 2004 database generated a total of **13,054**, **14,879**, **16,618** flight arrivals in rush hour 1, 2, and 3, respectively.

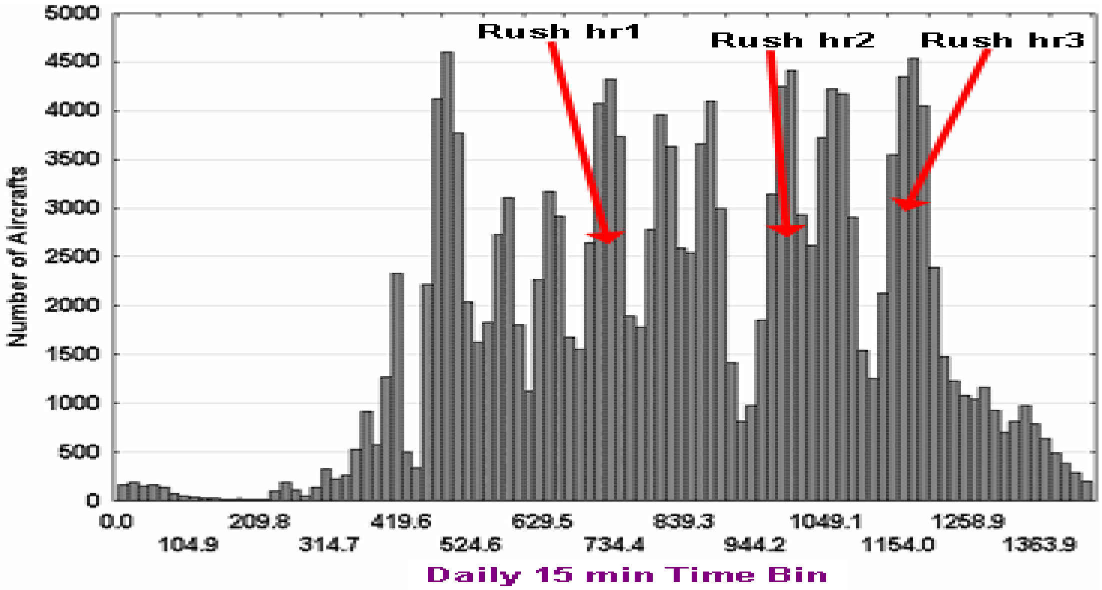


Figure 36. 2004 IAH Airport Daily Cumulative Airport Arrival Rate Distribution

The conventional metrics for TMA evaluation are listed in Table VI**.** We carried out analysis on variances and averages of delayed arrivals using the 1st, 2nd, 3rd and 4th metrics, and on arc-to-arc flight distance saving and quality of service (QoS) of different arrivals applying the 5th and 6th metrics.

Table VI. Performance Metric Definitions

Concept	Variable		Description
Conventional Metrics	1st	**Average arrival delay**	Average of the difference between scheduled and actual arrival time over all flights
	2nd	**Arrival delay variance**	Variance of the difference between scheduled and actual arrival time
	3rd	**Average >15 min arrival delay**	Average of excess time delay of flights that have arrival delays greater than 15 min
	4th	**Unreliability**	Proportion of flights with arrival delays over 15 min
	5th	**Flight Distance**	Distance traveled between the arrival arcs en route to runway
	6th	**Runway Arrival Distribution**	Arrival distribution on runway entry points
Proposed Metrics	1st	**Distribution Distortion Index (DDI)**	Degree of distortion in arrival pattern of flights
	2nd	**Quality of Service (QoS)**	Level of Traffic Arrivals

1. Differential Analysis of Arrival Traffic Delays During Rush Period

The application of the first four metrics showed that the average delay in all three-rush periods reached individual peaks in June 2004 before any noticeable improvement began to occur. Likewise, noticeable improvement did not begin to show until June 2004. Notably, rush hour 3 of the post-TMA duration generated the greatest improvement having exhibited greatest decrease in average delay between June and August 2004 as shown in Figure 37. On the other hand, Figure 38 shows that rush hour 3 variances of arrival delays during post-TMA were much higher than the others. However, the arrival delays variance of arrivals, from July to August of 2004, are much lower than the pervious months.

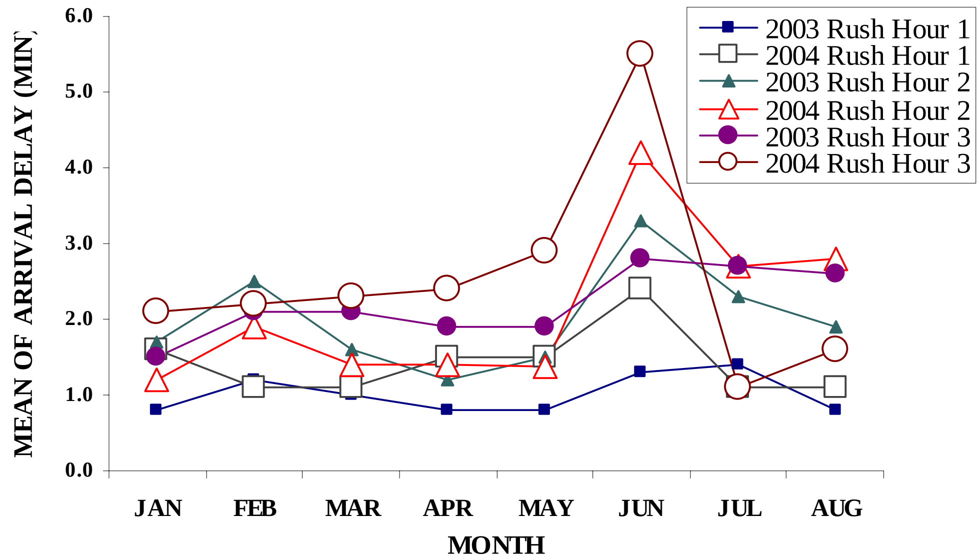


Figure 37. Average of Arrival Delay

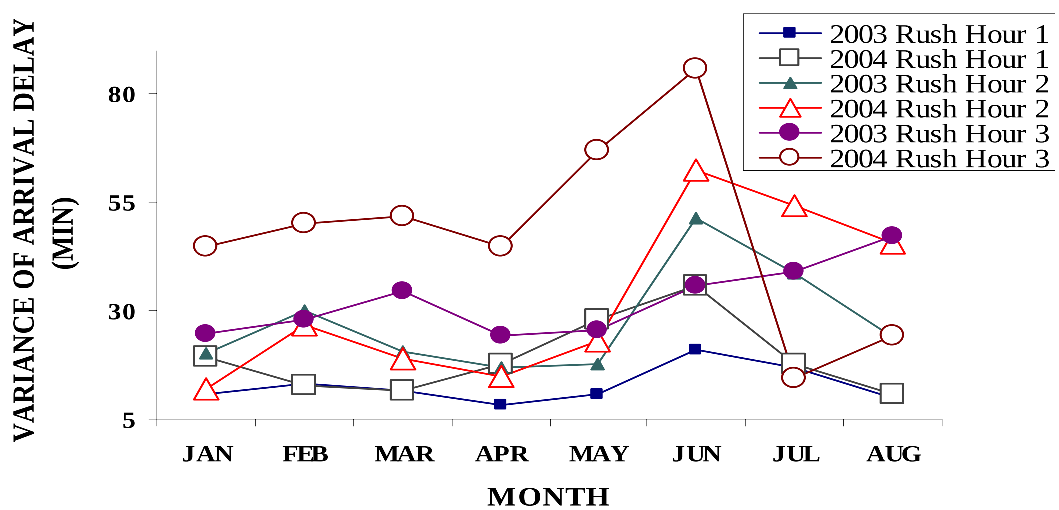


Figure 38. Variance of Arrival Delay

Next, we analyzed the average of extended delay time of flights whose arrival times were greater than scheduled time of arrival plus extra 15 minutes (i.e. arrival times greater than STA + 15 minutes). These simply represent all arrivals in excess of 15 minutes, divided by the total number of flights. Figure 39 shows that the mean of extended delayed arrivals over 15 minutes, during rush hour 3 of the post-TMA duration, yielded lower extended delay averages compared to others. Rush hour 2 period of post-TMA experienced the lowest averages of extended delays over 15 minutes in April 2004.

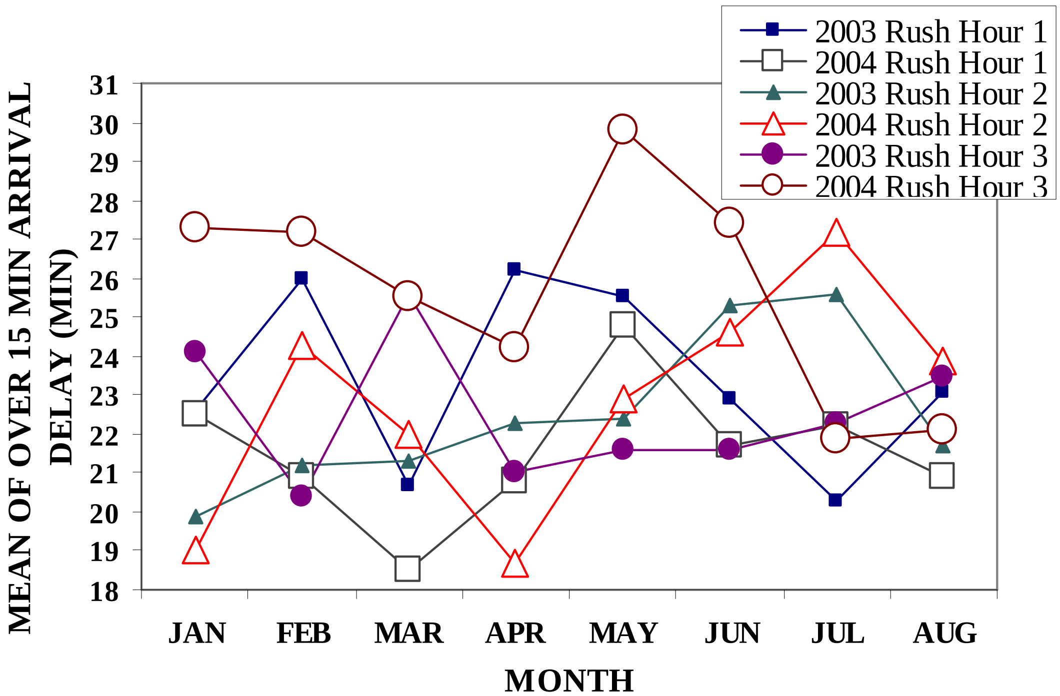


Figure 39. Average Delays of Flights with ≥15-Minute Delays

Next, we analyzed those portions of flights that experienced a delay in excess of 15 minute, out of all the arrivals. This metric could be interpreted as the unpredictability of arrivals. In Figure 40, we see that the value of unpredictability reached its peak in June 2003 and 2004 for all three-rush periods. Moreover, we notice that the level of unreliability of arrivals began to improve in June of 2004; meanwhile, the greatest improvement occurred during rush hour 3. Thus, we can conclude that the level of unpredictability of arrivals at IAH during post-TMA period was higher compared to pre-TMA but the differences were not very significant. In rush hour 3, for example, our analysis shows that 6% (5%) of the whole arrivals in post-TMA (pre-TMA) experienced delays greater than 15min.

2. Flight Distance Analysis

In addition to the throughput, arrival delay, and airport arrival distribution analyses, we also analyzed the flight distance changes between the four arrival arcs that are within a radius of 200 nautical miles from IAH Airport. The arcs around IAH airspace include:

- Extreme Arc (EA) at 200 nautical miles to IAH
- Outer Arc (OA) at 160 nautical miles to IAH

- Inner Arc (IA) at 100 nautical miles to IAH
- Meter Arc (MA) at 40 nautical miles to IAH

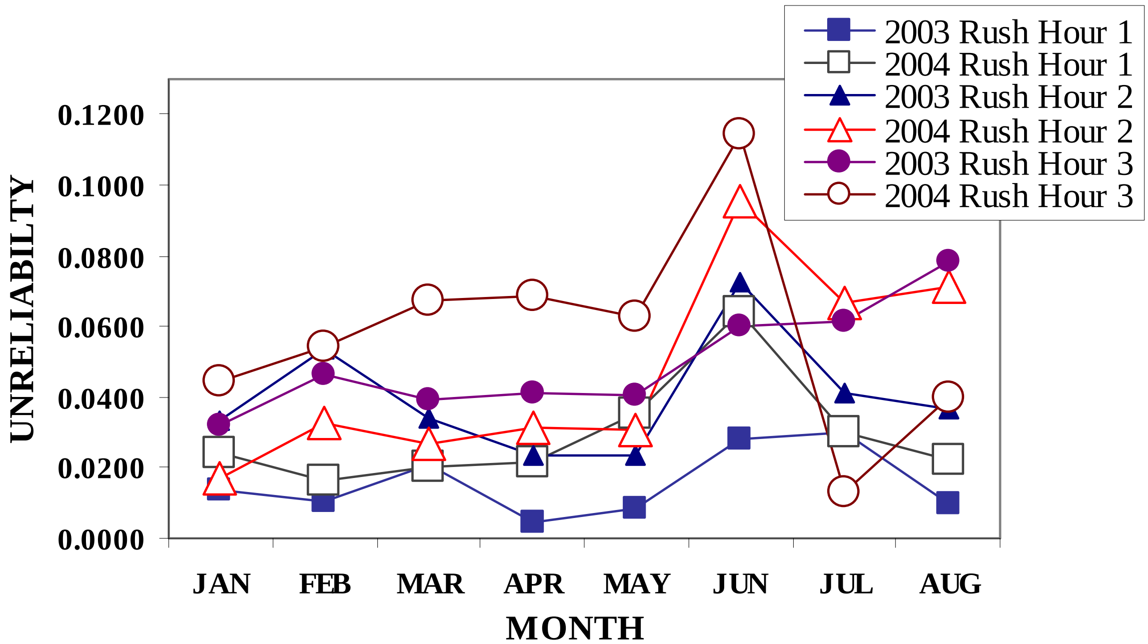


Figure 40. Proportion of Flight that Experienced ≥15-Minute Delays

Again, for this analysis we compared the pre-TMA duration (January 2003 to August 2003) with the post-TMA (TBM) duration (January 2004 to August 2004). Our analysis was based on only rush hour 3, from 1857 to 1957 local time, because this period experienced the greatest number of arrival traffic for both pre- and post-TMA durations. Conclusively, there were statistically significant reductions in flight distance covered by arrival aircrafts, during rush hour 3 for the two durations under consideration. The reduced flight distance occurred for all flights between the Extreme Arc (EA) to Outer Arc (OA), Outer Arc (OA) to Inner Arc (IA), Inner Arc (IA) to Meter Arc (MA), and Meter Arc (MA) to the runway (RW).

As in Figure 41 the mean flight distance between the Extreme Arc (EA) and Outer Arc (OA) was 43.3 nautical miles for the pre-TMA duration, and 42.9 nautical miles for post-TMA duration. This indicated a 0.4 nautical mile reduction of flight distance traveled by each flight. We see that the mean flight distance covered by aircraft between OA and IA was 66.3 nmi for pre-TMA and 64.9 nmi for post-TMA, which yielded improvement of 1.4 nmi per flight. The analysis shows that the mean flight distance covered by aircrafts between IA and MA was 64.9 nmi for pre-TMA and 63.8 nmi for post-TMA; thus, indicating a 1.1 nmi flight distance saved per flight during the post-TMA duration. Lastly, we observed that the Meter Arc (MA) to runway (RW) flight distance varied only by a small percentage and that the change for post-TMA was not statistically significant.

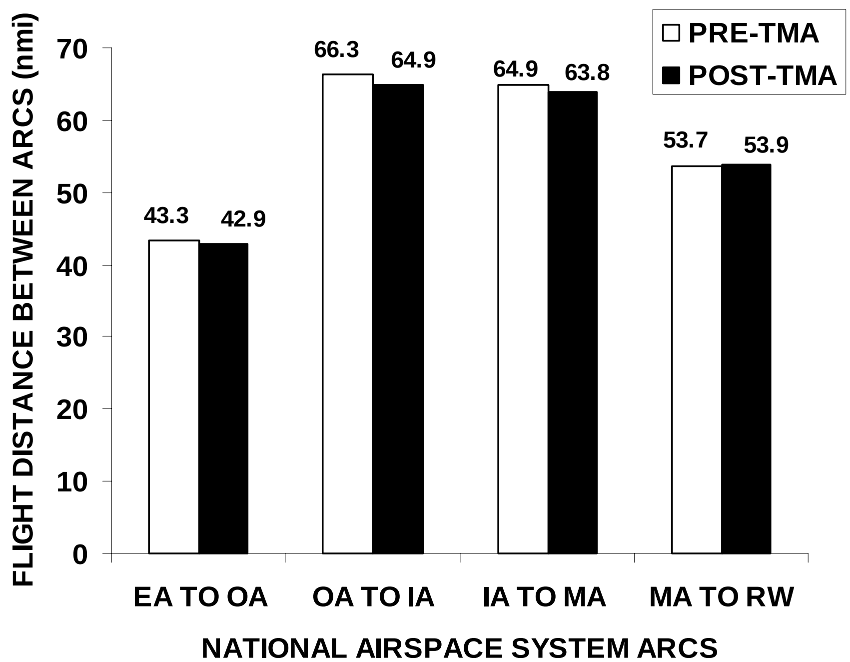


Figure 41. IAH Flight Distance Comparisons for Pre- and Post-TMA Duration

In addition to the comparison of mean flight distance covered by aircrafts in-between the arrival arcs, we performed comparison analysis of their standard deviations as shown in Figure 42.

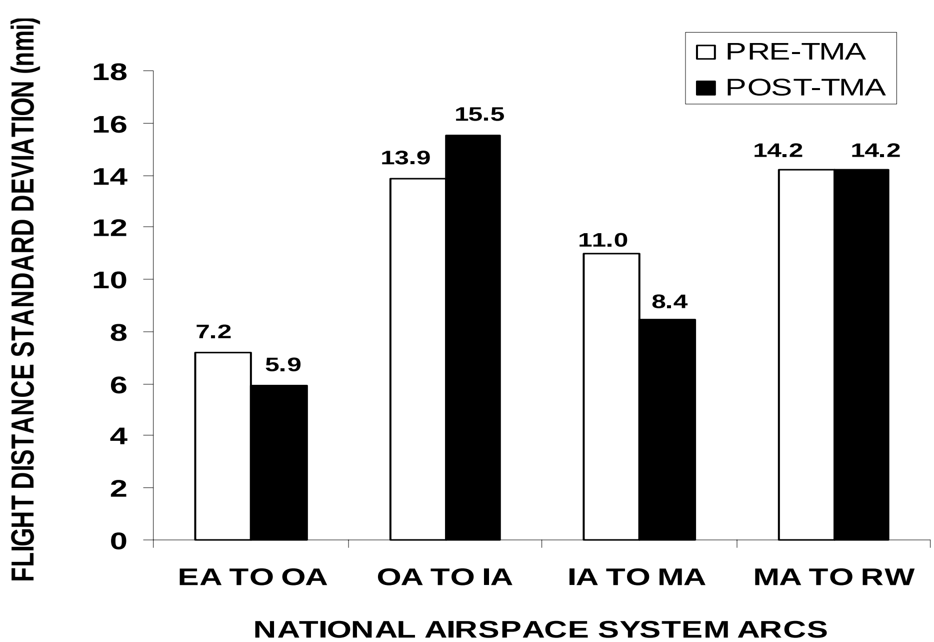


Figure 42. IAH Arrival Flight Distance Deviations

The standard deviations of two particular flight distances were smaller for post-TMA compared with that of pre-TMA. For the pre-TMA duration, the flight distance covered differ by about 18.1 % for flight distance covered between the Extreme Arc (EA) and Outer Arc (OA); by 23.6

% for the flight distance covered between the Inner Arc (IA) and the Meter Arc (MA). The standard deviation of flight distance covered between the Outer Arc (OA) and Inner Arc (IA) was higher in post-TMA by about 11.5 % while the flight distance covered between the Meter Arc (MA) and the runway (RW) by arrival aircrafts had no significant difference for both pre- and post-TMA durations.

Table VII summarizes that the percentage increase in number of arrival flights at IAH during the post-TMA period. Although each month of the post-TMA duration recorded significant percentage increase in number of arrival flights compare with the previous year (pre-TMA duration). The month of February had the greatest percentage increase.

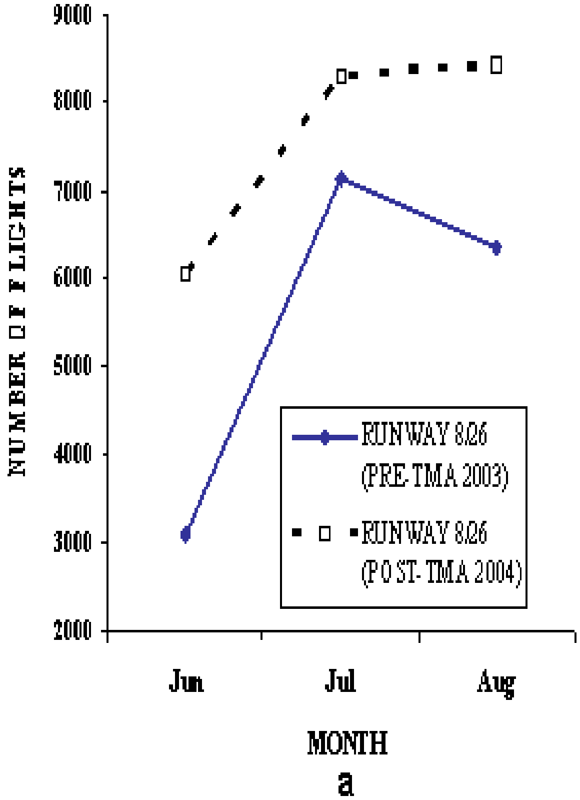
Table VII. Flight Arrivals during Peak Arrival Period of Rush Hour 3

Month	**Pre-TMA Flight Arrivals (2003)**	**Post-TMA Flight Arrivals (2004)**	**% Increase**
JAN	1155	1876	+ 62.4
FEB	897	1740	+ 94.0
MAR	1192	1948	+ 63.4
APR	1519	1820	+ 19.8
MAY	1679	1826	+ 8.80
JUN	1606	1622	+ 1.00
JUL	1900	2000	+ 5.30
AUG	1721	1998	+ 16.1

3. Runway Arrival Distribution

In terms of runway utilization, there was 23 % increase in the triggered uniquely identified flights (UIFs) in post-TMA compared with pre-TMA. For the runway analysis, we considered all daily operations. We analyzed runway operational performance from June to August 2003, which refers to Pre-TMA without time-based metering duration, and June to August 2004, which refers to post-TMA with time-based metering duration. Figure 43 (a) and (b) and Figure 44(a) and (b) show monthly arrival distribution of trigger arrival traffic on the four operational IAH airport runways.

Runway 9/27, Runway 8/26, and Runway 15R/33L had 14.7 %, 25.1 %, and 171.2 % increase in trigger traffic arrivals for 2004 compare with 2003. In 2004, only runway 15R/33L (often used for general aviation purpose) recorded a percentage decrease (11.3 %) of arrival traffic operation. Most importantly, there was a steady increase in triggered arrival traffic over Runway 8/26, Runway 9/27, and Runway 15R/33L. However, Runway 9/27 recorded a 4.4 % and 7.6 % decrease of arrival traffic operation between July and August 2004. Meanwhile, Runway 15L / 33R was the least utilized runway for arrival traffic operations.



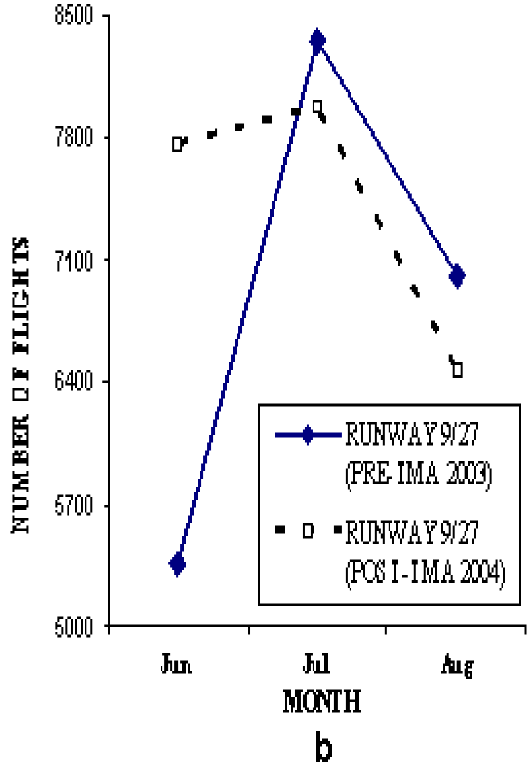
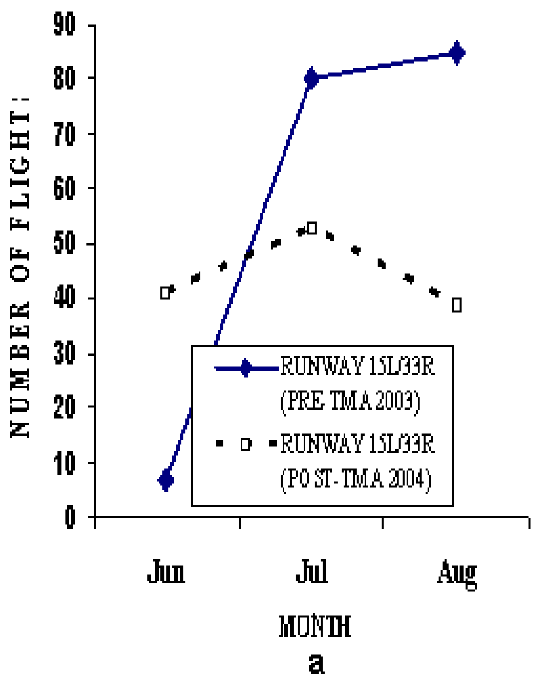


Figure 43 (a) and (b). Arrival Distributions over Runway 8/26 and Runway 9/27



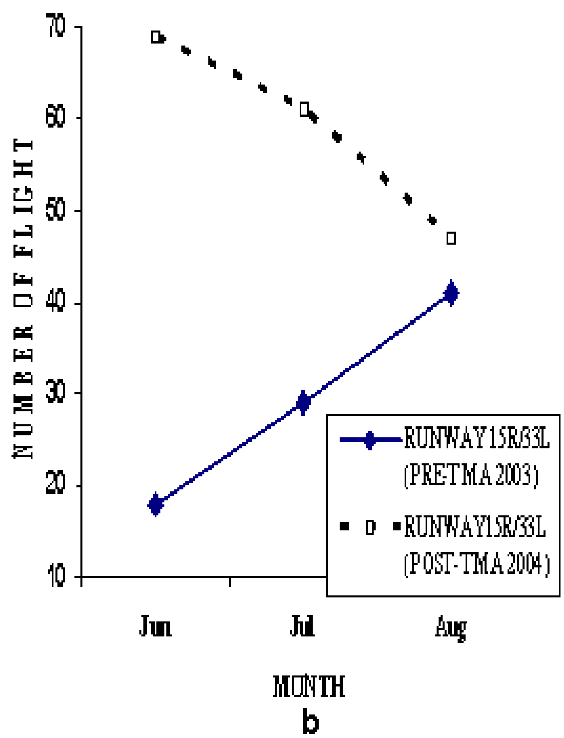


Figure 44 (a) and (b). Arrival Distributions over Runway 15L/33R and Runway 15R/33L

Next, we analyzed the landing approach at each runway entry point. Figure 45 shows a pictorial view of how triggered arrival traffics approach the entry points of individual runways for the pre- and post-TMA duration. In pre-TMA duration, there was a 98.8 % difference between the number of triggered flight arrivals at Runway 26 and Runway 8. Also, the approach entry points of Runway 27 accommodated 98.9 % of triggered flight arrivals in pre-TMA duration (2003). Again, in the post-TMA duration (2004), the triggered flight arrivals at the approaching entry point of Runway 9 increased from 1.1 % in 2003 to 3.2 % in 2004 at Runway 9/27. There was no triggered arrival at the approaching points 33R and 33L in both 2003 and 2004.

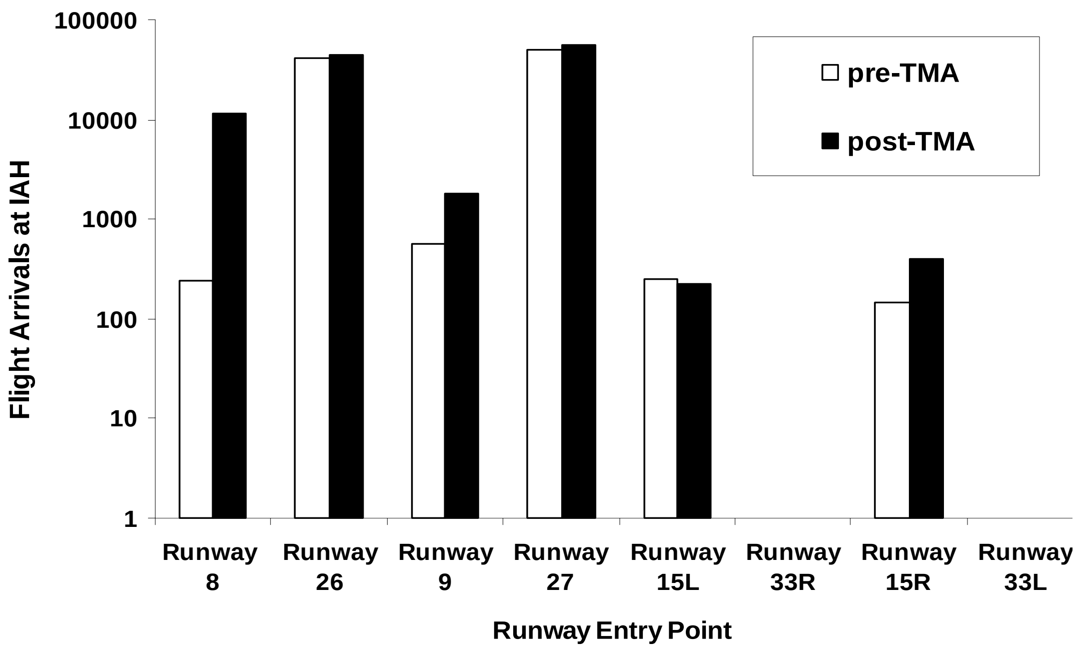


Figure 45. Arrival Traffic at Runway Entry Points for Pre- and Post-TMA

D. IAH Arrival Analysis for TMA Evaluation using New Metrics

1. Differential Analysis of Arrival Traffic Distribution During Rush Period

In this section, we applied the first proposed metric referred to as the "Distortion Distribution Index" (DDI). The DDI is defined as a statistical measure of distortion of airport arrival rate distribution from an ideal distribution of uniformity. Airport acceptance rate (AAR) is defined as the maximum number of aircraft per hour that can be scheduled to land at a particular airport. Figures 46 and 47 show 10 min bin AAR of cumulative daily rush hour aircraft arrivals for both pre- and post-TMA, respectively.

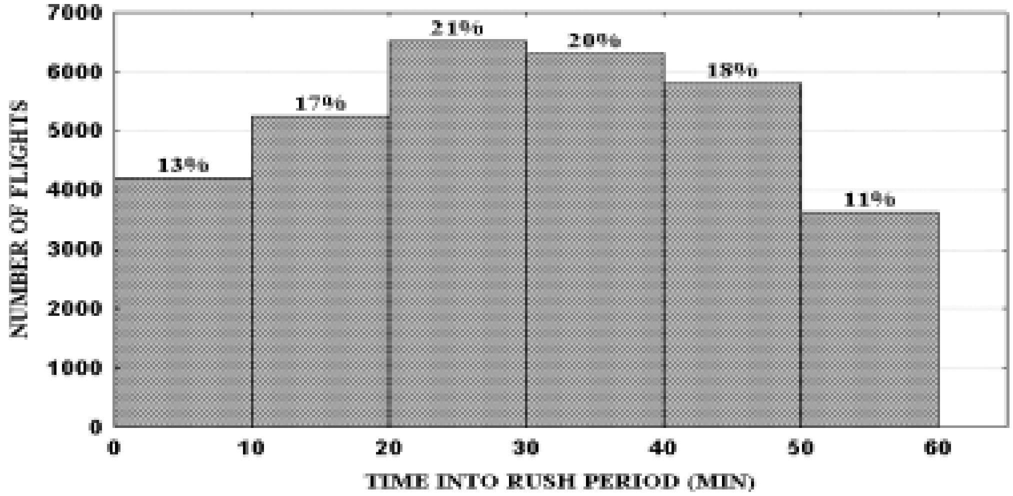


Figure 46. Superimposed Daily Rush Periods for Runway Arrival Time in 2003

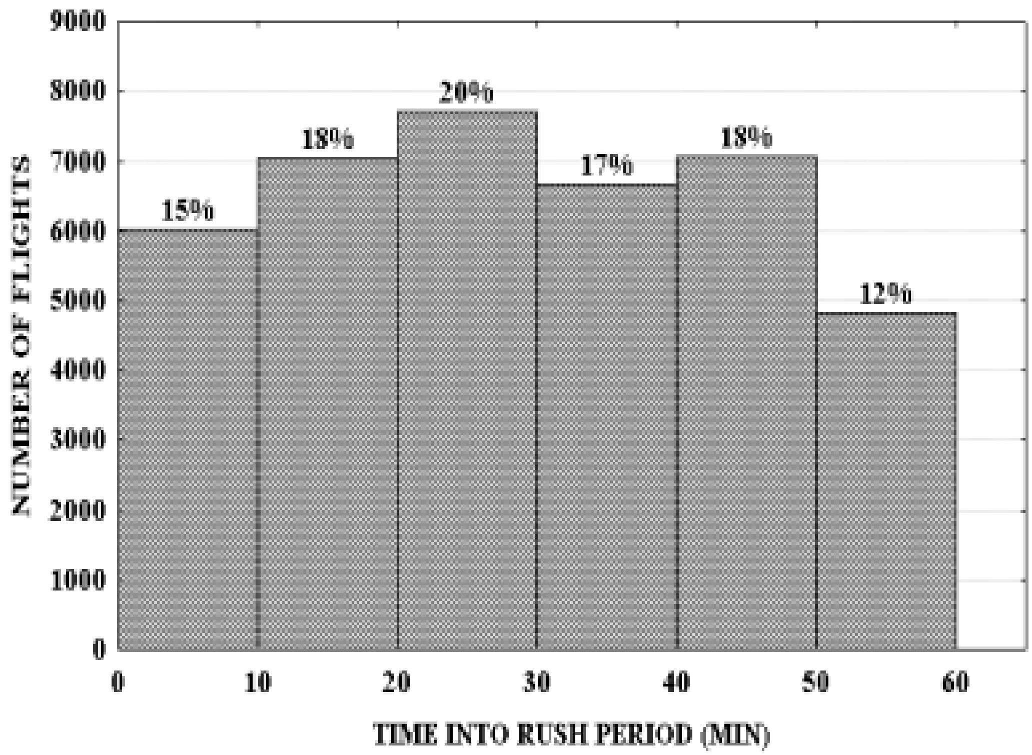


Figure 47. Superimposed Daily Rush Periods for Runway Arrival Time in 2004

We notice that arrivals in pre-TMA were more erratic and unbalanced compared with those of post-TMA. So, we applied the distortion distribution index (DDI) so as to determine the degree of distortion in flight arrivals. DDI is said to be the measure of the evenness in arrival distribution across the six 10 min intervals of the rush hour periods under consideration. An ideal arrival distribution is one that has the same number of arrivals in each 15-minute interval (with the value of DDI as 0). However, in an extreme case where all arrivals occurred in a single 15-minute interval while other intervals have zero arrival (with the value of DDI as 1). A lower DDI value would indicate well-balanced airport arrival rate distribution and significantly reduced instances of exceeded airport capacity.

Figure 48 shows the result of the distribution obtained when the DDI concept was applied to flight arrivals in the first six months of pre- and post-TMA durations. The DDI of flight arrivals for months in 2004 (post-TMA duration) were lower than those of 2003 (pre-TMA duration) except for March, in which same DDI values were obtained for both years. The lowest value of DDI (i.e. flights' with evenly spaced 15 min bins arrival distribution) occurred in the month of June, 2004. The occurrence of the lowest arrival distribution at IAH, in June 2004, is not a coincident since full implementation of the traffic Management Advisor with Time-based metering (TBM) began at the same month. However, we observed that the month of March produced the same value of distortion distribution index (IDD).

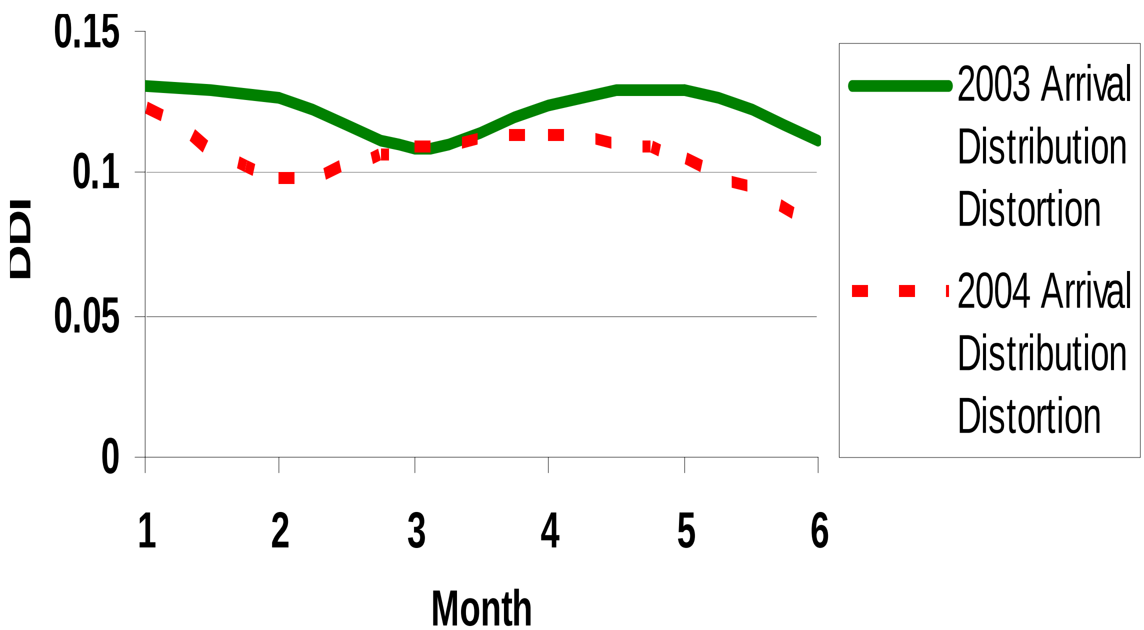
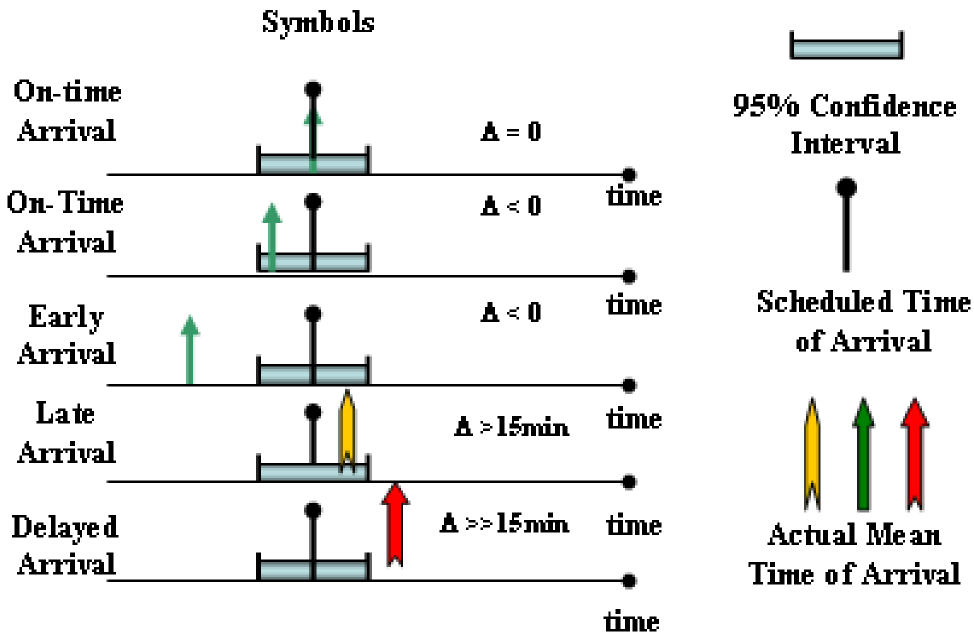


Figure 44. Distributed Distortion Index of 2003 and 2004 Arrivals in Rush Periods

2. Quality of Service Analysis of Arrival Traffic during Rush Period

This analysis focused on the capability to deliver an expected level of Quality of Service (QoS). The Federal Aviation Administration (FAA) would have to provide a consistent and predictable QoS to the commercial airline carriers if it desires to optimally provide customer service at minimum cost and at maximum profit. Current NAS QoS is based on arrivals and departures that occur either on scheduled time arrival (STA) or at least 15 min after STA as shown in Figure 49.



Δ = (Actual Mean Time of Arrival) – (Scheduled Time of Arrival)

Figure 49. Graphical Representations of Trigger Statistics vs. Actual Time Metrics

The conventional QoS does not specify any form of confidence level. Therefore, we reiterate that the provision of a QoS without accounting for some form of specific level of service consistently contributes earnestly to the shortcomings of expectations between both the airline operators (customers) and the FAA (service provider). The various QoS levels proposed for the analysis are shown in Table VIII.

Table VIII. Definition of Quality of Service Levels

QoS Level	**Difference Between Actual Mean Arrival Time And Scheduled Time of Arrival**
1	+ 15.0 minutes
2	+ 22.5 minutes
3	+ 30.0 minutes
4	+ 37.5 minutes
5	+ 45.0 minutes
6	+ 52.5 minutes
7	+ 60.0 minutes
8	+ 67.5 minutes
9	+ 75.0 minutes
10	> + 82.5 minutes

We have already defined uniquely identified flights (UIFs) as flights that had ≥ 4 monthly arrivals in either the pre- or post-TMA duration. The actual mean time of arrivals of any particular trigger UIF is the sample average arrival time of individual flights in a specified UIF group. We considered all possible population mean time of flight arrival for the entire flight arrivals from January to August 2003 and January to August 2004.

For QoS analysis, we used the actual mean arrival time to categorize performance of the NAS in relation to individual triggered uniquely identified flight arrival statistics at IAH.

For rush hour 1 period (see Figure 50), all triggered flights had a QoS level of 1 in pre-TMA (an approximate of 100%); while post-TMA observed 98.8% of Triggered flights with QoS of level 1. Furthermore, unlike pre-TMA that had no triggered flights with QoS level of 2 or 3, the post-TMA duration of rush 1 observed 1 % and 0.2 % trigger flights with QoS level of 2 and 3 respectively.

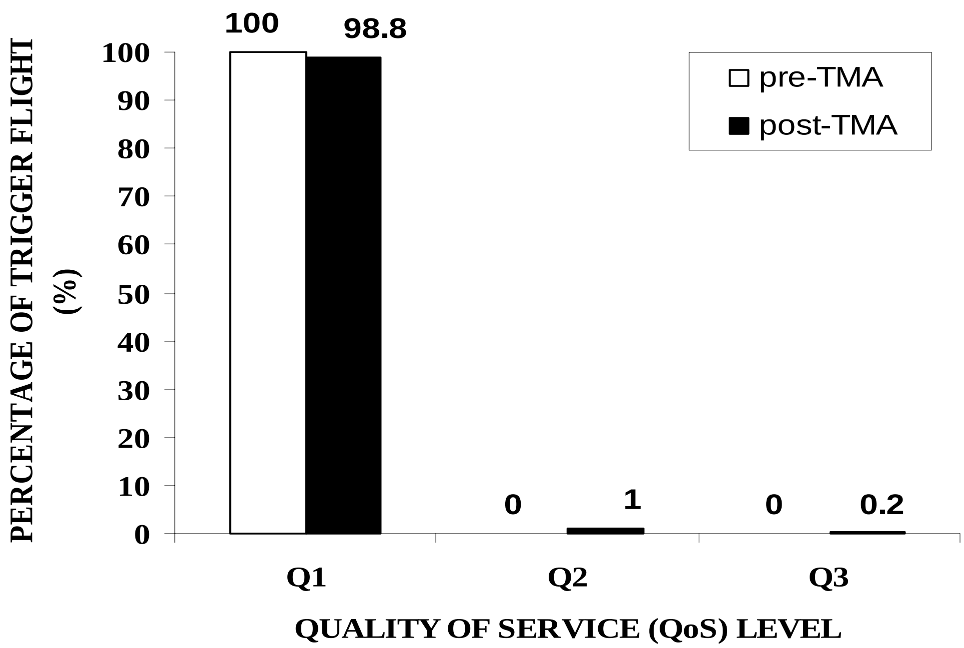


Figure 50. Quality of Service Classification for Rush Hour 1 Period

For rush hour 2 (see Figure 51), even though the percentage of trigger flights that had QoS1 were higher in pre-TMA (about 99.3 %) compared with post-TMA, which had 98.5 % of triggered flight that has QoS level 1. Also, pre-TMA observed 0.2 % trigger flights that had a QoS level 4 compared with post-TMA which had none.

On the other hand, Rush hour 3 recorded the highest number of triggered arrivals in both pre- and post-TMA (see Figure 52). Although, rush hour 3 accepted more trigger flights for both the pre- and post-TMA durations, the post-TMA duration was still able to manage a 97.6 % of triggered flight that had QoS level 1 compared to the pre-TMA duration that observed 98.5 % trigger flights with QoS level 1.

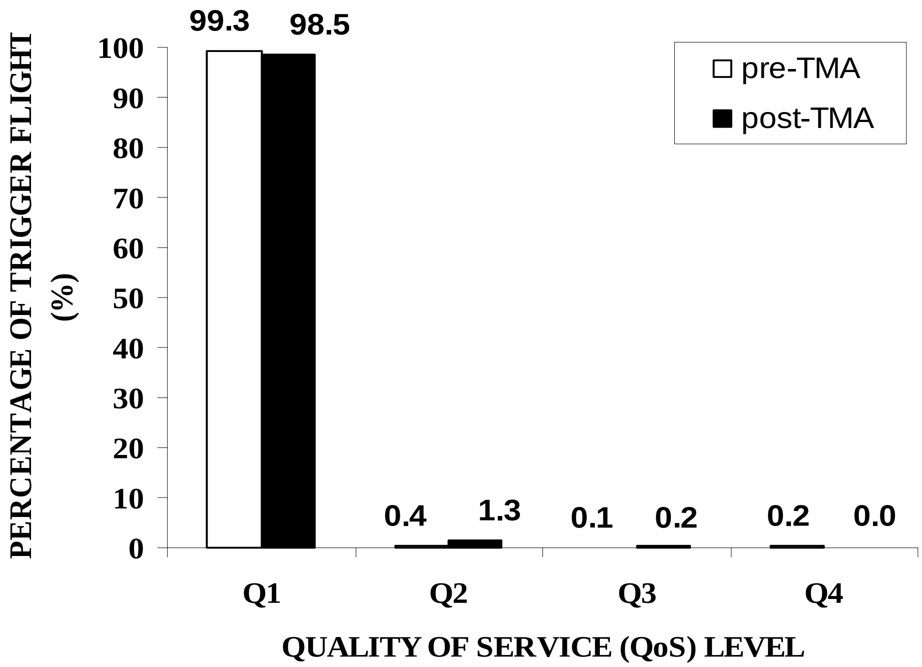


Figure 51. Quality of Service Classification for Rush Hour 2

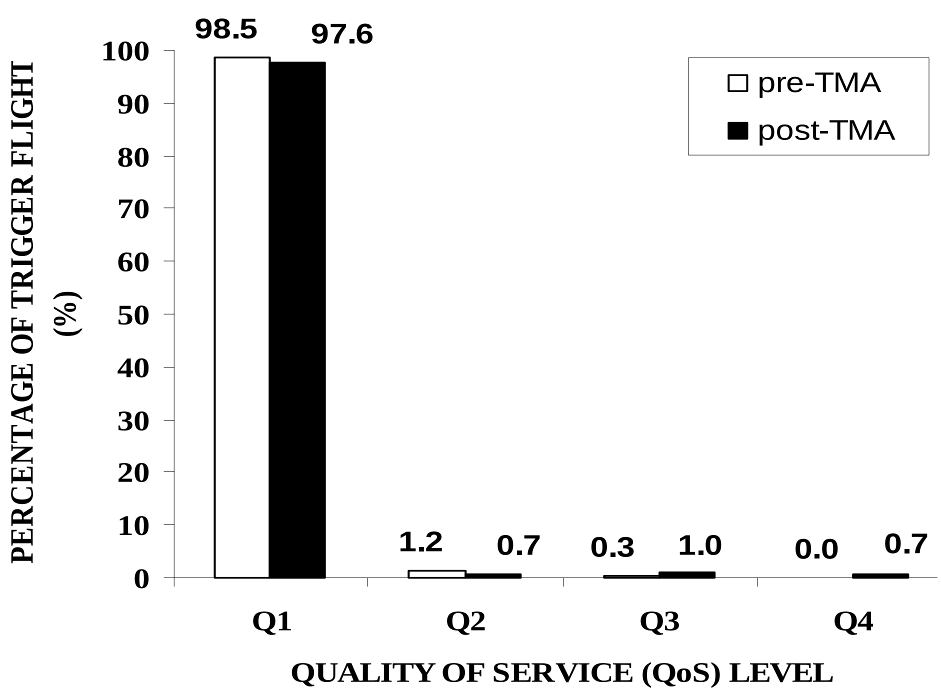


Figure 52. Quality of Service Classification for Rush Hour 3

E. Modeling and Simulation of IAH Arrival Traffic using Arena®

The arrival traffic model developed and simulated in this report imitates the real life airport operations that occurred at IAH during a selected peak arrival period.

Most companies in the aviation community use simulation-based training when their employees require training on dangerous or expensive equipment. Simulations allow the user to observe the impact of their choices without the outcomes having any impact on the real operation. Thus, a model developer can learn how to respond to emergencies, how individual actions and decisions affect entire processes, and how to operate complex pieces of equipment. The simulation provides the opportunity to observe how all the different arrival traffic flight operations work together. This approach allows the user to gain a perspective of the interactions and correlations between the arrival flight operations at IAH. The simulation gears the user to focus on the integration, interaction, and correlation of all the components in the arrival traffic operation and provides the user with a learning environment that is equivalent to the actual airport operation system itself. In addition, the following benefits can also be obtained from the arrival traffic simulation:

- **Cost**: Experimenting in real life is costly. It's not only the capital expenditure of hiring aircrafts to hold between arcs but it's the cost of the consequence of making these decisions. What if the traffic controllers close one of the runways and then find that they cannot cope with the workload of arrival traffic? The only cost with simulation is the software and the man-hours to build the simulation.
- **Repeatability**: It's really difficult to repeat the exact circumstances again in real life; so, you only get 1 chance to collect the results. It is also difficult to test different ideas under the exact same circumstances. So how do you know which idea is really the best? For example, what is the effect, on arrival throughput, of building a new runway at IAH? With simulation you can test the same system again and again with different inputs (i.e. random input variables).

- **Time**: If you want to know whether adding another meter fix at IAH local airspace will reduce aircraft waiting queue over the next 2 years then you'll actually have to wait 2 years. However, with simulation you can run 2, 10, or even 100 years into the future in seconds. So you get the answer now instead of when it's too late to do anything about it.

- **Communication**: Because the arrival traffic simulation is visual and animated it enables clear description of its purpose to others. Thus, it's more convincing than just displaying the end results as people can not see where these came from. Presently, simulation is so effective at communicating ideas that many companies now use it as a sales tool to sell their products.

Arena is a simulation software tool manufactured by Rockwell Automation that can/has been used to solve numerous intricate problems by mimicking the behavior of actual systems. Arena could be implemented in the study of systems that measure performance, improve operations, or design a model that does not exist. Its application can be expanded not only to the arrival analysis, but also to the following traffic areas: An airport with departing passengers checking in, going through security, going to the departure gate, and boarding; departing flights contending for push-back tugs and runway slots; arriving flights contending for runways, gates, and arrival crew; arriving passengers moving to baggage claim and waiting for their bags; and the baggage-handling system dealing with delays, security issues, and equipment failure [28].

To build a model using Arena, we need to open a new model window and place the required modules on the screen. We note that the basic building block of Arena models are called "modules." The modules are sub-divided into the flowchart and data modules and they both define the process to be simulated and are chosen from panels in the Project bar. The flowchart modules describe the dynamic processes in the model, while, the data modules describe the characteristics of various process elements, like entities, resources, and queues. After naming individual modules, the resulting model window is similar to that shown in Figure 53.

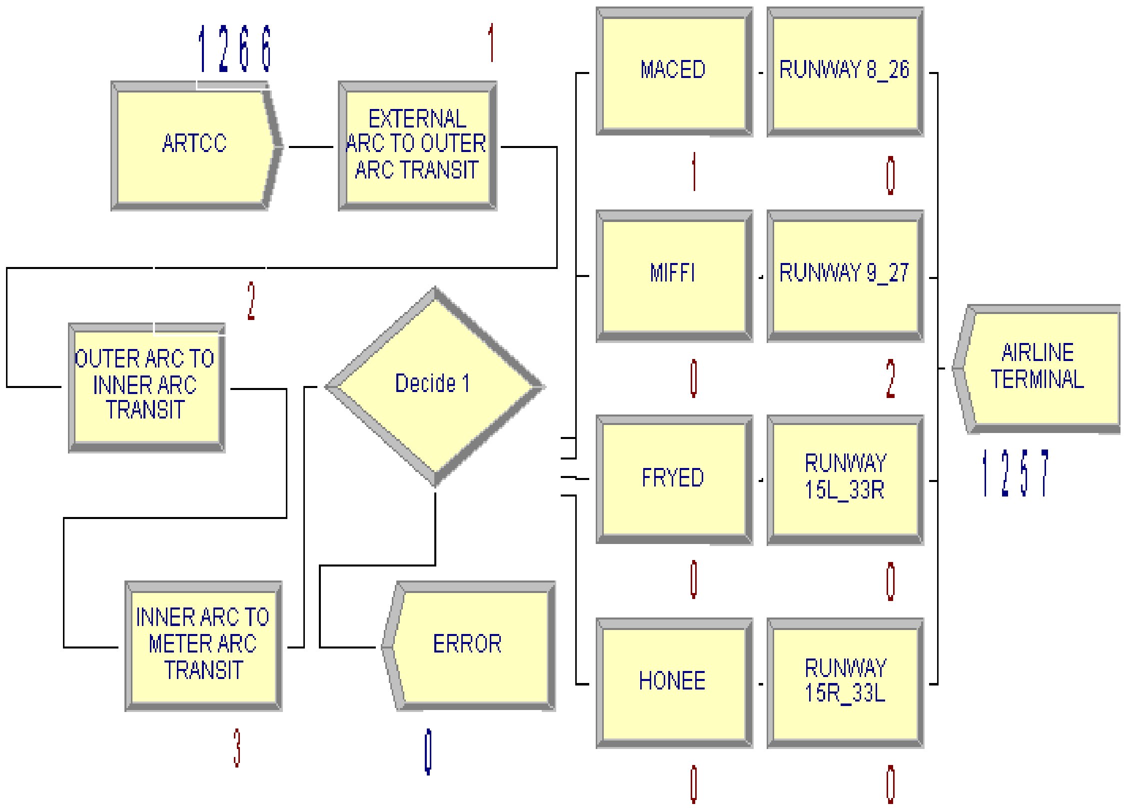


Figure 53. Arena Arrival Traffic Model

The "ARTCC" module simulates flight arrivals at the external arc (EA). The inter-arrival time of all flights that arrived at IAH, during rush hour 3, were exported from the 2004 IAH database into Arena Input Analyzer, which determines the best arrival distribution that closely imitates the inter-arrival characteristics of arrival flights at the EA. In addition, the Input Analyzer generates a mathematical expression, which is used as an input in the "Create module." For instance, the mathematical expression generated by Arena Input Analyzer for the inter-arrival times of arrival flights at the EA is given by -0.01 + EXPO (3.72). Figure 54 shows graphical distribution of flights' inter-arrivals at the EA. The mathematical expression defines an exponential distribution of mean equal to 3.72, shifted to the left by 0.01. The same procedure is repeated for the other modules except for the decision module.

For instance, during rush hour 3 in January 2004, the mathematical expressions generated by the Arena Input Analyzer for the transition time of each arrival aircraft between the arcs en-route to IAH are given below:

- Transition Time between EA to OA = NORM (5.57, 2.03)
- Transition Time between OA to IA = NORM (9.12, 2.76)
- Transition Time between IA to MA = 7 + 16 * BETA (6.46, 24.7)
- Transition Time between MA to RW = 7 + LOGN (7.91, 3.6)

Meanwhile, the decision module named "Decide 1," simulates the sequencing of flights that arrive IAH from different geographical locations through the meter fixes that are located around the Meter Arc (MA). The decision module helps to ensure that flights that have been scheduled to land on a particular runway actually pass through the appropriate meter fix.

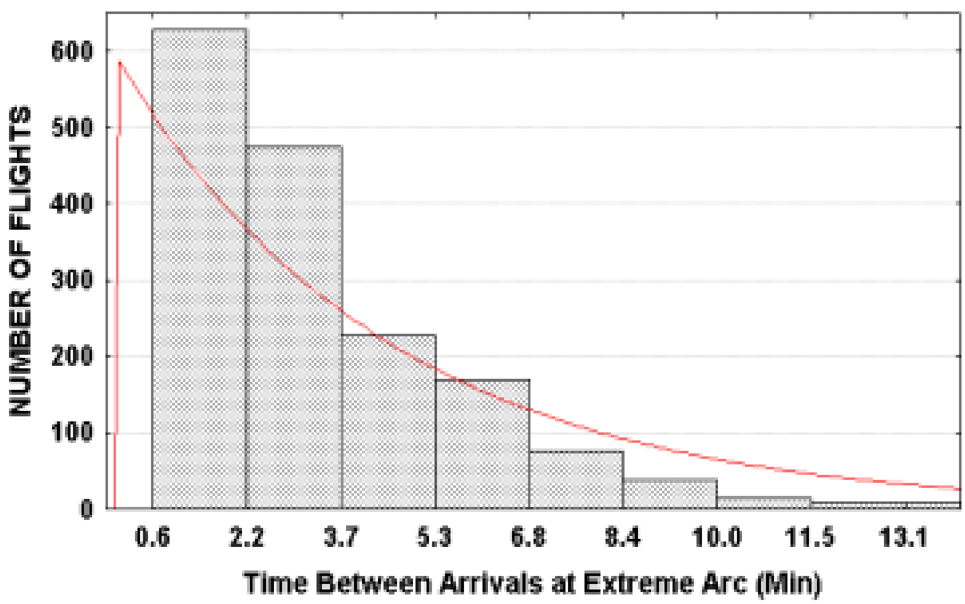


Figure 54. Extreme Arc Inter-Arrival Distribution for rush hour 3 in January 2004

The meter fixes at IAH airport airspace are simulated in the model by the MACED, MIFFI, FRYED, AND HONEE modules. All arrival flights must pass through one of the fixes before final approach to a runways. Arrival flights passes through specific meter fix based on which geographical location (west coast or east coast) they are coming from. An animated version of the arrival traffic simulation model is shown in Figure 56. The animation was made possible by the introduction of the transfer modules, such as the Route transfer modules, which allow the transfer of the generated aircraft entities from one station to the other without direct connection between respective stations.

Figure 56. Arrival Traffic Animation View on Arena Window

Once the necessary mathematical expressions have been generated and entered into the respective modules, the model can now be simulated for all peak period from 1857 to 1957 local time, in minute, for the first seven months in 2004. The simulation was run for a cumulative inter-arrival time at the EA, for 20,000 replications. This time was chosen so that all flights that cross the EA are considered in the final simulation output. We performed the same procedure to arrival traffic at IAH for the remaining six months (from February to July 2004). Next, we compare the results obtained from the simulation and from the direct analysis of arrival traffic delays from the database.

As for the simulation result, the differences between the database and simulated output analysis are not very pronounced. For instance, in January 2004, the database analysis results vs. simulation results of the transition time of the arrival traffic from EA to OA, OA to IA, IA to

MA, and MA to RW produced percentage change of 0.01 %, 0.18 %, 0.23 %, and 0.46 %, respectively (see Tables IX and X).

Table IX. EA to OA and OA to IA Transition Time Comparison Analysis

Month	DB Analysis	Simulated Analysis	DB Analysis	Simulated Analysis
	EA to OA (min)	**EA to OA (min)**	**OA to IA (min)**	**OA to IA (min)**
JAN	11510.8	11512.0	18856.8	18823.0
FEB	10679.0	10941.0	17504.2	17479.0
MAR	11656.3	11670.0	19384.7	19374.0
APR	10831.0	10771.0	17965.6	17946.0
MAY	10620.7	10643.0	17880.6	16118.0
JUN	9570.6	9634.7	16128.2	16247.0
JUL	11323.1	11289.0	18348.1	18315.0

Table X. IA to MA and MA to RW Transition Time Comparison Analysis

Month	DB Analysis	Simulated Analysis	DB Analysis	Simulated Analysis
	IA to MA (min)	**IA to MA (min)**	**MA to RW (min)**	**MA to RW (min)**
JAN	21215.4	21265.0	30806.5	30666.3
FEB	19832.1	19778.0	29599.8	14995.7
MAR	21460.5	21362.0	33777.5	33684.2
APR	20451.4	20329.0	31794.1	31670.6
MAY	20429.8	20218.0	32099.2	32180.9
JUN	18136.1	17981.0	26380.4	26231.7
JUL	21186.4	21029.0	31976.9	31877.2

Similarly, the same month produced percentage change of 0.47 %, 0.50 %, 5.0 %, and 2.5 % for runway 8L/26R, runway 9/27, runway 15L/33R, and runway 15R/33L, respectively (see Tables XI and XII).

Table XI. Runway 8L/26R and Runway 9/27 Traffic Comparison Analysis

Month	DB Analysis	Simulated Analysis	DB Analysis	Simulated Analysis
	RWY 8L / 26R	**RWY 8L / 26R**	**RWY 9 / 27**	**RWY 9 / 27**
JAN	983	978.4	1074	1068.6
FEB	931	926.8	965	960.4
MAR	1063	1059.0	1056	1052.2
APR	1032	1028.0	967	963.0
MAY	984	981.0	1050	1046.6
JUN	848	845.2	942	938.8
JUL	1145	1140.6	1036	1032.1

Table XII. Runway 15L/33R and Runway 15R/33L Traffic Comparison Analysis

Month	DB Analysis	Simulated Analysis	DB Analysis	Simulated Analysis
	RWY 15L / 33R	RWY 15L / 33R	RWY 15R / 33L	RWY 15R / 33L
JAN	2.0	2.1	8.0	7.8
FEB	0.0	0.0	1.0	0.9
MAR	0.0	0.0	2.0	1.9
APR	2.0	2.0	8.0	8.0
MAY	1.0	1.0	2.0	1.8
JUN	4.0	4.0	9.0	9.0
JUL	6.0	5.8	2.0	2.0

The model and simulation proposed in this report would assist air traffic controllers and traffic management coordinators to predict future flight arrivals and it also provide an alternative means of economically performing contingency analysis on airport arrival operations.

IV. TMA Evaluation of En-Route Traffic

A. Introduction

This chapter evaluates TMA operational performance on en route arrival traffic, unlike the one we described in the preceding chapters that focused on overall departure-to-arrival analysis, at George Bush Intercontinental Airport (IAH) especially in the months June through August, 2004 for comparison analysis with a pre-TMA year (June through August, 2003).

The analysis is focused on the arrival features from en route to runway, including average arrival time, variance, min and max time in minutes, and speed in nautical miles (nmi) per hour for the arrival flights, as well as the calculation of fuel consumption per gallon by aircraft types for the arrival flights to compare them in 2003 and 2004 rush periods. Lastly, a simulation of the en route arrivals was performed that shows the accumulated time spent per month and the number of gallons consumed in fuel from en route to runway by aircraft types.

The focus on TMAis to see if TMA can reduce delays at en route and terminal by reducing flight time and increasing capacity, provide a smoother flow of traffic by negotiating restrictions that are "just in time, and just enough" and to note if delays will be shifted from a region of lower altitude to a region of higher altitude where fuel would be less consumed.

The problem in previous works is the uncertainty and/or the varied departure time of flights. To solve this problem of departure time discrepancy, our method of arc-to-arc analysis would eliminate the departure uncertainties and, therefore, the time and distance analysis in en-route would provide us a fair evaluation of TMA performance. Aircraft must pass through the en-route domain to arrival airport. This new position was regarded as our reference point whereby every aircraft that reaches this point in the national airspace system would automatically start at zero time (our new start time and start position). From this new start position, the time of flight is therefore recorded until the aircraft lands, and our analysis of TMA from en route to runway using the arrival arcs is thereby performed.

There are three distinctive features in the approach of the evaluation of TMA during three different peak periods occurring in a day at IAH is in three parts. The first part involves the performance of statistical analysis of various types such as the calculation of the Min, Max, Variance, and Average of flight times spent between the arcs as well as the total time spent from en route (extreme arc) to runway, performance of delay analysis, speed analysis, chi-square analysis, and distance arrival distribution analysis. The reason for performing these different statistical analysis is to note the areas where TMA is having the greatest impact and also to be able to compare the results with a non-TMA period.

The second part includes the use of flight explorer to evaluate TMA's improvement or impact in November 2005 during a period when there was no construction or obstruction of any kind at IAH airport. The use of the flight explorer provides us with the 'last straw' in trying to evaluate TMA's effectiveness for the period on which no FAA database is available. It provides more of verification and validation of TMAs operational impact, extended from the given data recording period of FAA database.

The third feature involves the use of a simulation tool for simulation and modeling of flight times at the arcs. The simulation results may not be fully accurate because certain elements were not considered such as weather, the runway closure during TMAs evaluation, and the accurate count of the number of aircraft types, etc. However, the simulation provides us with insights as to the extend of TMAs impact during the selected rush periods at IAH.

The database of flight statistics given to us by the Federal Aviation Administration (FAA) contained several columns of information such as callsign of flights, the departure airports from which the flights departed, the runways at the arrival airport, months and dates of arrival flights, and times spent and distances covered by the flights in 2003 and 2004.

According to FAA, TMA was implemented at Bush Intercontinental Airport in August 2003, however, [29] showed that TMA time based metering (TBM) did not begin until mid-December 2003. Therefore, the first 8 months of the years 2003 and 2004 are selected as the periods of comparison for TMA performance in arrivals based on times spent between arcs and distances covered in nautical miles from en route domain to runway.

In 200, there were a total of 161,084 arrivals while in the 2004 analysis, there were a total 167,733 arrivals at IAH between January to August. These arrivals were uniquely identified based on callsign, departure airport, runway, and month. That is, all the flights that had the same callsign, departure airport, runway and month were grouped and labeled UIF4 (uniquely identified flights by the four attributes: callsign, departure airport, runway, and month). Callsign represents a combination of the airline carrier name and the flight identification number; for example, COA162 where COA means continental airline and 162 is the number of the flight. If there are seven COA162s and five AA1298s that occurred in a year, they will be labeled as two separate UIF4s and are considered to be triggered flights. Triggered flights are those flights that appeared or arrived at IAH four times and more a month.

Those aircrafts arrived at IAH three times or less a month are not included in this analysis. The four flights and above per month rule was implemented so that at least 81 percent of the arrivals could be captured and analyzed. Six to ten flights and above per month would only generate about 40 to 60 percent of arrivals at IAH which would provide a poor result on our analysis.
In the 2003 data as well as the 2004 data of arrivals, it was observed that some records were missing. As a result, all those callsigns having blanks, zeroes, or null in certain fields were discarded because it would distort the analysis for the average, max, or min times spent and distances covered. With the discarding of these callsigns, the 2003 and 2004 arrivals further reduced to 91,396 and 115,475, respectively. On these arrivals, our analysis was performed on the times spent between arcs and the distances covered for a rush period.

B. En Route Traffic Analysis

1. Average Time Between Arcs

A delay analysis was necessary in order to know what month contained the largest amount of delays and how TMA was affecting these delays. In the analysis, the number of UIF arrivals was broken down into per month basis to enable us to analyze the delay of time spent between the arcs. The UIF arrivals in 2004 were significantly greater than the UIF arrivals in 2003 except for the month of June in which 2003 had 30 extra UIFs. Table XIII gives the breakdown of UIF arrivals per month.

Table XIII. Number of UIF arrivals per month for rush period 3

Month	2003	2004
1	76	138
2	69	147
3	92	186
4	117	161
5	150	160
6	157	127
7	139	152
8	142	173
Total	942	1244

The time spent between the arcs was evaluated in order to know what region or arc segments were experiencing delays. The greater the delay being experienced in any arc region per month the greater the fuel consumption would be. In this analysis, our primary focus was for the months of June through August since TMA time based metering did not begin until mid-December 2003 at IAH.

The average time spent between ea_oa for 2003 and 2004 were almost identical for each month. But as we pay closer attention to the times spent between the oa_ia, ia_ma, and ma_rw we begin to note some changes or delays occurring. For example, in Figures 54 and 55, more times were spent at the oa_ia arc region between June and August of 2003 than June through August of 2004.

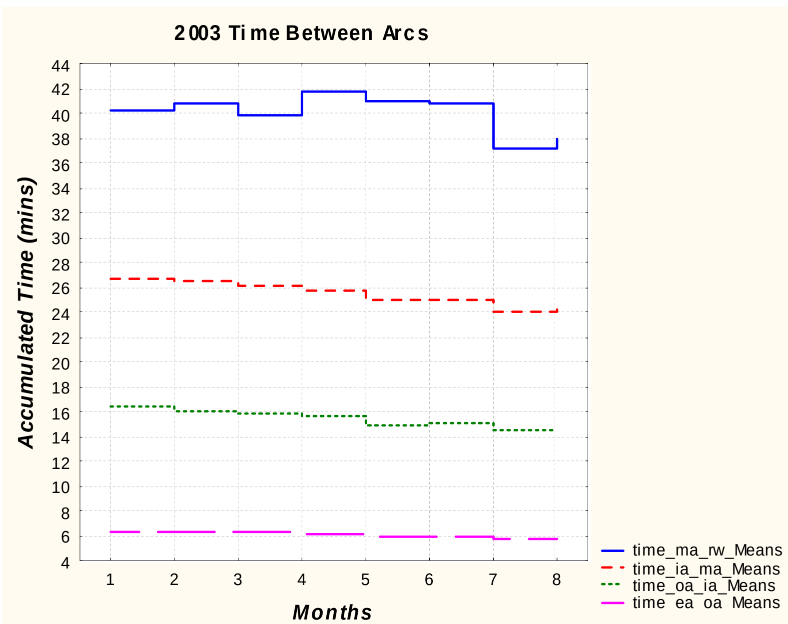


Figure 54. Time Between Arcs for 2003

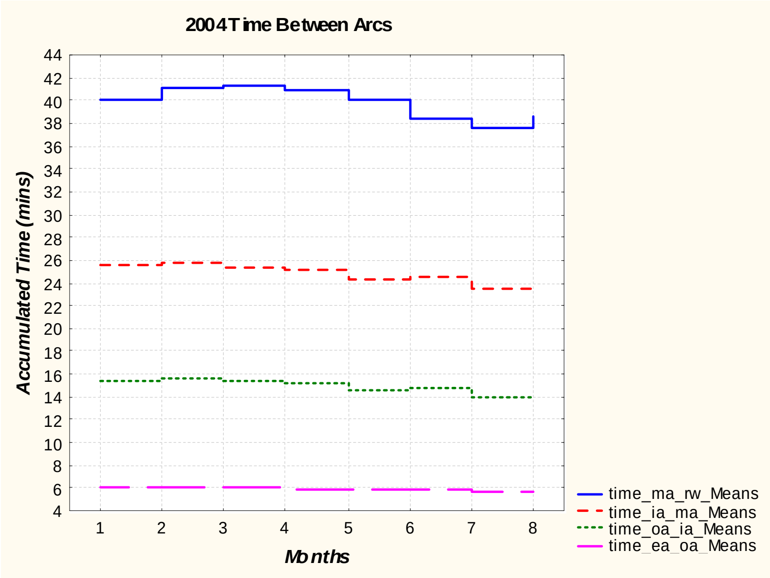


Figure 55. Time Between Arcs in 2004

Though the difference in time of the delays might be small overall, the delay times when summed up for each flight accumulates quickly.   The times shown on the y-axis is the accumulated times beginning from the extreme arc ending at runway. For instance, in June of 2004 time spent from extreme arc to the runway was a few seconds above 38mins while in June of 2003, the accumulated time was approximately 41minutes ,which can be said of a saving of 2mins on average for the month of June for 2004.

Time spent in this segment when compared to time spent in the other segments is considerably and absurdly greater. Even though the distance covered at the ma_rw is the smallest at 40nmi, however, a greater amount of delays were occurring in this region.

Although, both graphs look similar and the times spent are almost identical, however, based on the number of UIF flights per month, we note that TMA was able to accommodate more flights with less or about the same time at the arc segments in 2004.

Next presented are the minimum, average, and maximum times the flights spent at the various arc segments. The largest amount of time spent at the ea_oa arc segment in 2003 occurred in February in both 2003 and 2004, however, the largest amount of time spent at the ea_oa arc segment occurred in June with approximately 11mins and 9 mins respectively both in 2003 and 2004. While at the oa_ia arc segment, the largest amount of time spent occurred in May and March also with approximately 14 mins and 23 mins respectively. Though there is no apparent pattern that shows TMA is better or that delay is being shifted from a lower altitude to a higher altitude, we nonetheless notice that the time range for July and August of 2004 is much smaller for July and August of 2003.

Figures 56 and 57 show the min, average, and max time at the ea_oa and oa_ia arc segments for the months of January through August of 2003 and 2004, respectively.

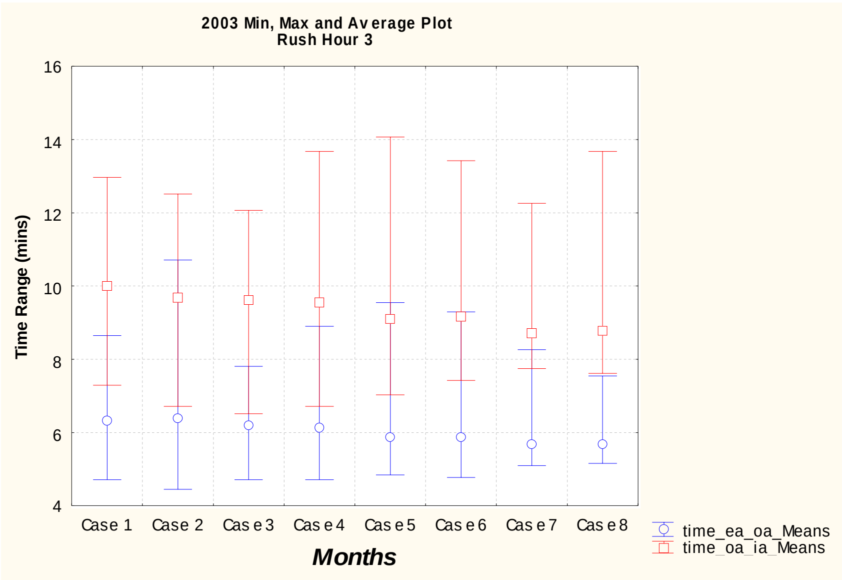


Figure 56. Min, Max, and Avg time at ea_oa and oa_ia arc segment for 2003.

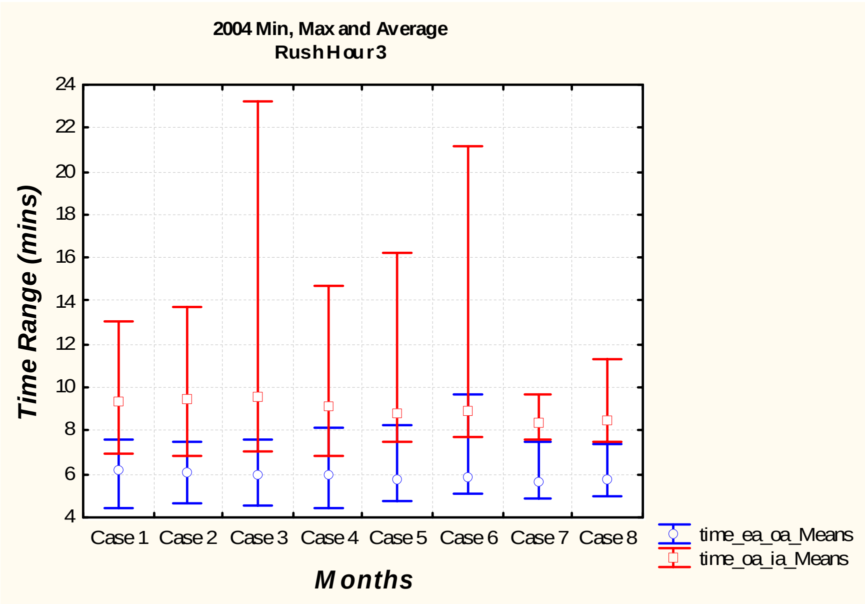


Figure 57. Min, Max, and Avg time at ea_oa and oa_ia arc segment for 2004.

Table XIV summarizes the total average time spent and distance covered in between the arcs for the entire eight months period.

Table XIV. Average and Variance of times spent and distances covered.

Average time spent and distance covered from ea_rw for the entire 8 months		
	2003	**2004**
Time(mins)	39.836	39.74
Dist.(nmi)	227.711	224.228
Average time spent and distance covered between arcs for the entire 8 months		
	2003	**2004**
Time(mins)	9.959	9.935
Dist.(nmi)	56.928	56.057

From the table, we see that in each category that the total time spent and distance covered were much improved in 2004.

2. Average Aircraft Speed between Arcs

As shown in Figure 58, speed plots for the 2003 and 2004 arrival flights were generated using the time and distance data of the FAA database. The left Y axis represents the speed of the arrival flights for the 2003 UIFs in nautical miles per hr while the right Y-axis represents the speed for the 2004 UIFs.

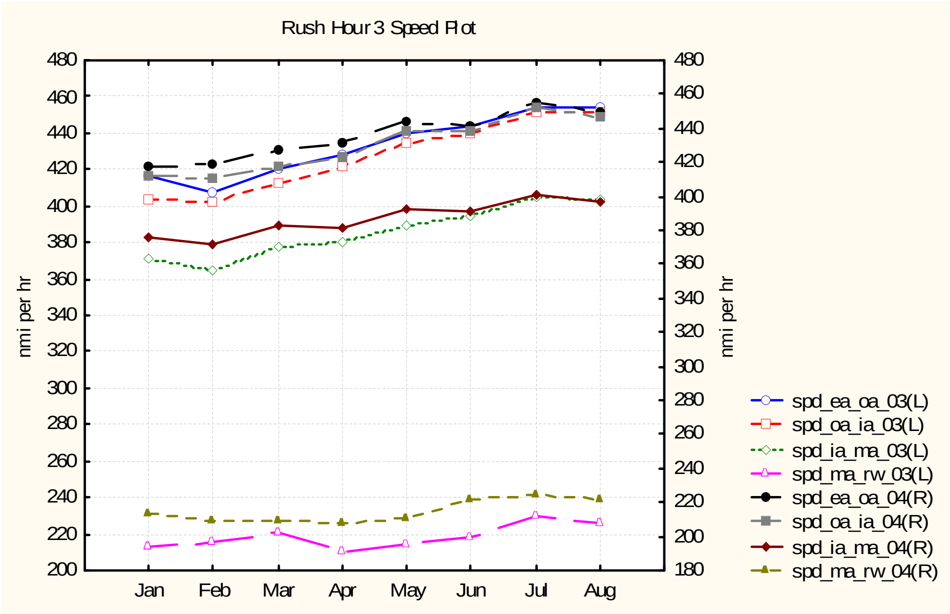


Figure 58. Speed plot in nautical miles per hour

The speed diagram shows an increase in speed in 2004 over 2003. This shows that the 2003 UIFs encountered more delay traffics that caused them to decelerate greatly thereby, burning more fuel from en route to runway. Also, further examination of the speed plot of 2004 reveals a shift in delay from lower altitude to a higher altitude especially in the month of August, showing TMA's effectiveness. Since TMA was fully operational starting in June 2004, there was a runway closure in effect which may have been affecting the performance of TMA. The month of August was the first month that saw all runways in operation with no closures or obstructions and TMA in full operation, the full impact of TMA was now starting to be seen.

C. Simulation of En-Route Traffic using Arena

We look into the simulation of arc arrivals based on the FAA database in simulating the times spent in each arc region, as well as calculating the number of gallons of fuel consumed by each aircraft type at a lower altitude for the pre-TMA and post-TMA of rush period 3 analysis. Within Arena is a standard tool called Input Analyzer. This tool is designed specifically to fit distributions to observed data, provide estimates of their parameters, and measure how well they fit the data [k9]. The usefulness of the input analyzer can be seen when a mathematical expression is needed to input into one of Arena building blocks. For instance, during the statistical analysis of the FAA data the runway inter-arrival times and times spent between the arcs were obtained for each month. In order to generate a mathematical expression that will be put into the Arena simulation, these runway inter-arrival times and times spent between the arcs were inputted into the input analyzer to provide a distribution and its corresponding mathematical expression.

When an input analyzer distribution is generated, it provides along with it the characteristics of that distribution. Figures 59 and 60 show examples of the distribution of runway inter-arrival time for June 2003 and time spent between meter arc to runway (ma_rw) distribution for August 2003.

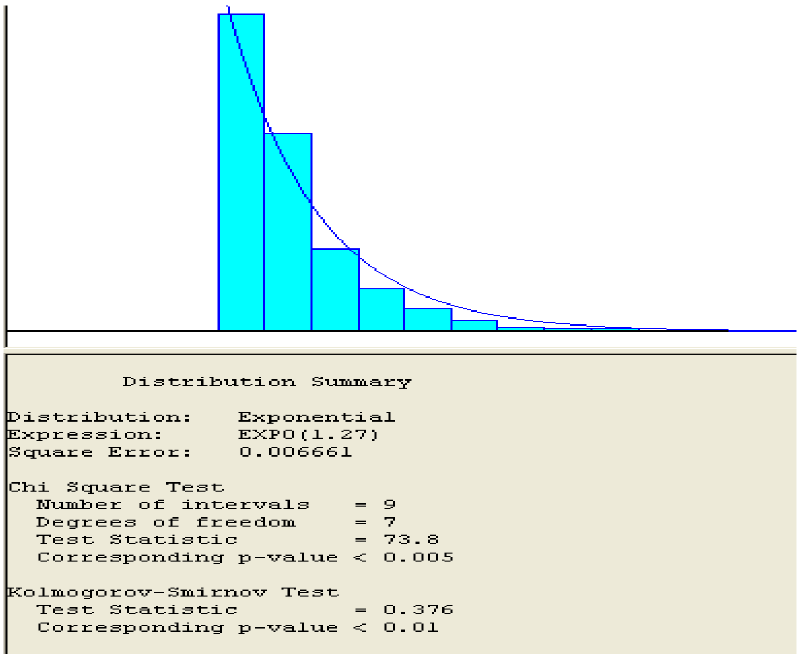


Figure 59. Distribution for Runway Inter-Arrival For June 2003

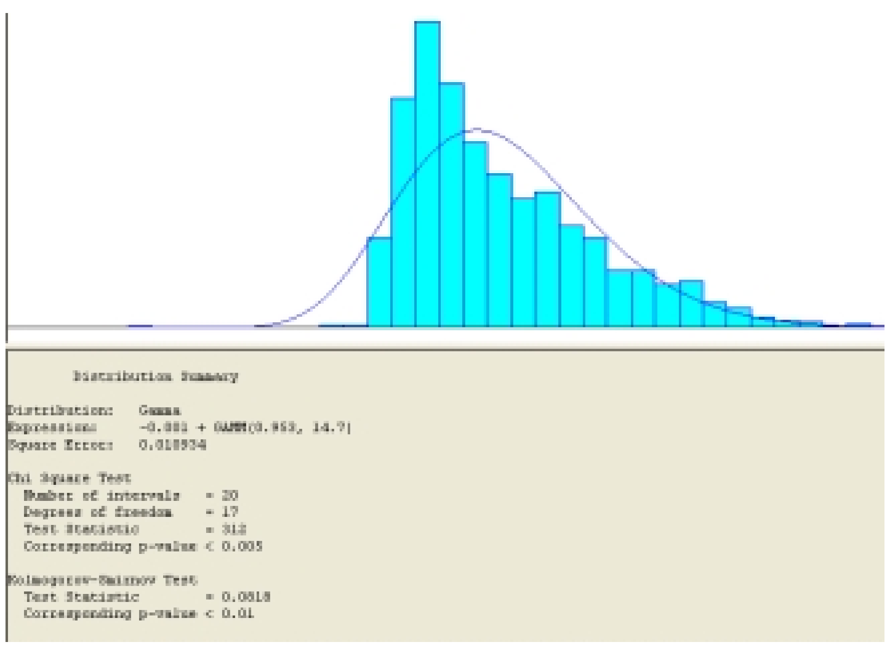


Figure 60. Distribution for runway inter-arrival for for the month of August 2003

For ma_rw fit, we note the mathematical expression of –0.001 + GAMM(0.953,14.7) which indicates that it's a gamma distribution showing its beta and alpha values and shifted to the left by 0.001. Also, of equal importance is the square error which helps to determine the mathematical expression and the best fit for a data. It's a measure of the quality of the distribution's match to the data. In other words, the larger the square error value, the further away the fitted distribution is from the actual data (and thus the poorer the fit). Of particular interest is the Corresponding p-value, which is always between 0 and 1.

Arena has different basic modules which are referred to as building blocks. To build a model, we need to open a new model window and place the required modules on the screen. After given corresponding names to each module, the model window would look like the one shown in Figure 61**.**

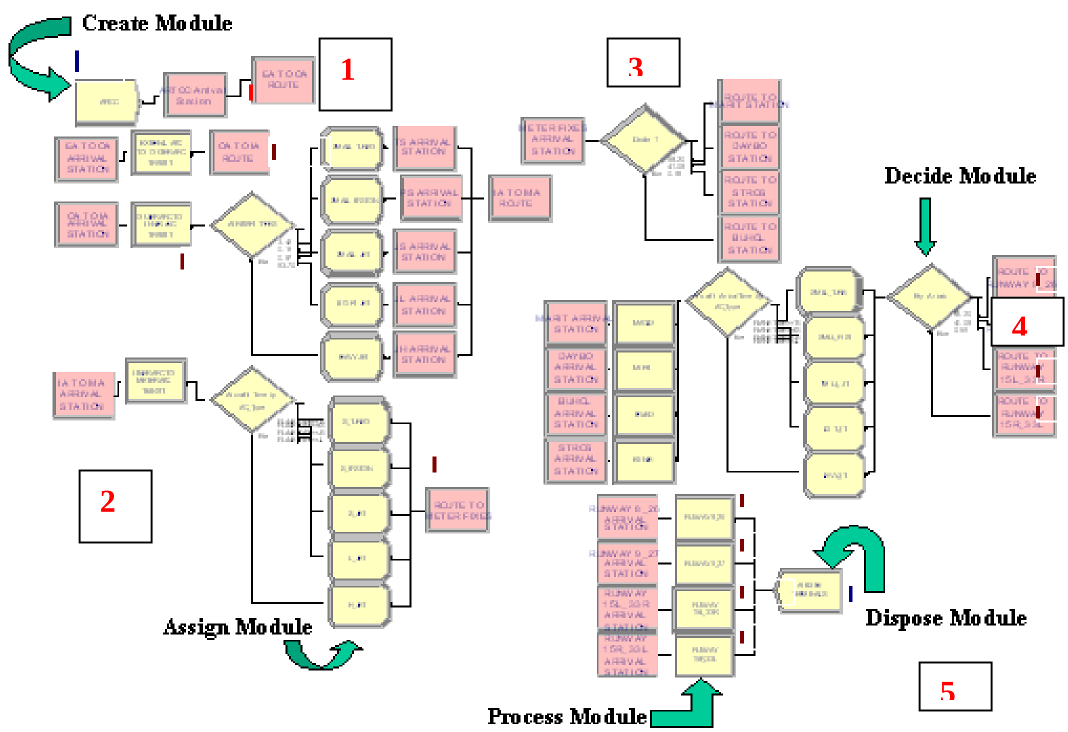


Figure 61. Arc-to-Arc Arrival Traffic Modeling in Arena

1. Variable Definition

For the modeling we defined a total of 5 variables namely: Create, Assign, Decide, Process, and Dispose modules. The colored modules were added for animation purposes and the numbers 1,2,3,4, and 5 describes the different stages of the modeling process. The first stage controls aircraft arriving at the external and outer arcs before separating them by their types. The second stage controls flight arrivals at the inner arc and calculates gallon fuel consumed in this arc region by aircraft types. The third stage groups the aircraft type arrivals at the meter arc meter fixes by percentages with respect to aircraft arriving from either north, south, west or east region of the country. The fourth stage controls the meter fix arrivals by aircraft types and assigns them attributes that allow for calculation of gallon of fuel consumption at the meter arc to runway. And the fifth stage orders aircraft type arrivals at the runways before disposing them to their terminals.

2. Model Development

Stage 1

The first step is to open each module and enter the required information required to complete the model. We begin with the Create module that will create the arriving aircrafts at the external arc by entering the mathematical expression for the extreme arc inter-arrival time generated by the input analyzer for the particular month that is being simulated. The inter-arrival time is entered in the "Time Between Arrivals" field and the units field is set to minutes. For example, the mathematical expression generated for the inter-arrival time for the month of August 2004 was – 0.001 + EXPO(4.4). Of importance is to realize that the Weibull and Exponential distributions offer better fits for inter-arrival times. Also, for the two process modules of the external arc to outer arc (ea_oa) and outer arc to inner arc (oa_ia), their expressions were entered as NORM(5.22,1.9) and NORM(8.41,2.04) respectively. These expressions accounted for the delay time experienced with the aircrafts traveling from ea_oa and oa_ia. Table XV shows the different expressions generated for the specific months of 2004.

Table XV. Mathematical Expressions for Variable for 2004

Month	Ea_inter_arrs	Time_ea_oa	Time_oa_ia	Time_ia_ma	Time_ma_rw	Rwy_inter_arrs
JUN	-0.001 + EXPO(4.98)	NORM(5.34, 1.9)	NORM(8.95,4.94)	7 + LOGN(2.99,1.31)	7 + LOGN(7.6,4.2)	-0.001 + EXPO(0.964)
JUL	-0.001 + EXPO(4.66)	NORM(5.16,1.75)	NORM(8.38,2.34)	7 + LOGN(2.63,1)	7 + LOGN(7.62, 4.24)	-0.001 + WEIB(0.212,0.308)
AUG	-0.001 + EXPO(4.4)	NORM(5.22, 1.9)	NORM(8.41,2.04)	7 + LOGN(2.76,1.15)	8 + LOGN(6.68, 4.6)	-0.001 + 11* BETA(0.336,4.81)

After entering the expressions for the ea_oa and oa_ia times spent, the next step is to identify these arrival aircrafts by their aircraft type ID and assign them their individual attributes. These aircraft type Ids were grouped by their percentages of arrivals. We observed that aircraft type JL had above 90% of arrivals for the three months shown in Table XVI.

Table XVI. Percentage of aircraft type

% Aircraft AC Type (2004)					
	Small Turbo (TS)	**Small Piston (PS)**	**Small Jet (JS)**	**Light Jet (JL)**	**Heavy Jet (JH)**
Jun	3.69	0.08	1.23	92.62	2.38
Jul	3.05	0.00	0.95	94.29	1.71
Aug	3.49	0.19	0.87	93.70	1.75

Since we are simulating the month of August, the percentages shown for the month of august

2004 was entered in the decide module. And the assign module contained attributes that would help identify the aircraft types and to perform the necessary calculations for each aircraft type. For instance, the attribute PLANE TYPE = TS lets the model know that this is a small turbo and the attribute ARRIVAL TIME = TNOW helps to record the current arrival time of the small turbo aircrafts.

Stage 2
The mathematical expression for the time spent between inner arc to meter arc (ia_ma) generated before entered into the process module. The decide module in this stage was used to maintain the plane type identification so that the earlier assigned attributes can be used to calculate the gallon of fuel consumed in this arc segment. For example, GFCTS (gallon of fuel consumed by small turbo) = RFCTS * Q_Time/60 where Q_Time = TNOW – ARRIVAL TIME which accounted for the delay time experienced by aircrafts traveling from inner arc to meter arc. The division by 60 was to convert Q_Time to hours.

Stage 3
In stage three, we merely redirect flights at the meter arc to their meter fixes in order to represent flights arriving from the north, south, west, and east regions of the continental U.S. Stage four displays four process modules of the meter fixes where flights would travel to their respective runways. The meter fixes were selected according to which runway is closest and in the path of the meter fixes. They represent the gateway through which every arriving aircraft passes through before arriving at runways. The first decide module identifies aircrafts by their plane types so that the attributes in the assign module can be used to calculate the delay time spent from meter arc to runway (ma_rw) as well as the gallon of fuel consumed in this arc segment. The second decide module displays arrival by aircraft types to the runways in percentages as shown in Table XVII.

Table XVII. Percentage of runway arrivals

% Allocation of Runway (2004)				
	15L/33R	**15R/33L**	**9\27**	**8\26**
Aug	0.59	0.14	41.08	58.20
Jul	0.27	0.09	47.33	52.31
Jun	0.22	0.50	52.25	47.03

From the above table, runways 9\27 and 8\26 were the most utilized while flights barely landed on runways 15L/33R and 15R/33L for each month of our analysis.

Stage 4
The model can actually run at this point, however once started, it would run non-stop because Arena does not know when to stop the simulation. Therefore, we established run parameters for the model by adjusting the ‘Replication Parameter’. We set the ‘Replication Length’ to 1 hour because the rush period 3 time frame from our analysis was from 18:57 to 19:57pm daily. The ‘Base Time Units’ was set to minutes, and the ‘Number of Replication’ was set to 30 since there are 30 days in a month and then defaulted the remaining fields. The animated version of the model discussed above can be seen in Figure 62. However, in enabling animation we introduced the station transfer modules (colored modules), i.e. the Route and Station module. The Route module allows for transfer of the aircraft entities from one station to the other without direct connection. We analyze parts of the outputs of this simulation in the next section.

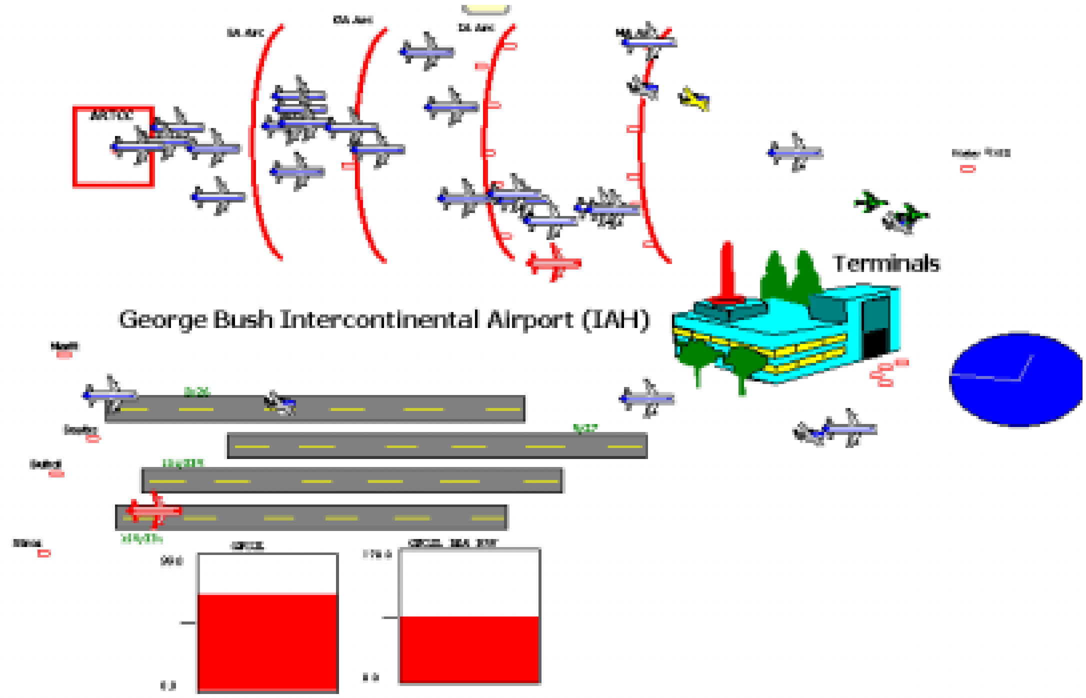


Figure 62. Arc-to-Arc Arrival Animation View on Arena Window

3. Discussion on the Model and Simulation Result

In this section, we provide a general summary of the results we obtained in the simulation for the time spent between arcs and compared them to the statistics obtained from the database analysis. In the original data, we observed a total of 1606, 1901, and 1722 arrivals for the months of June, July, and August of 2003 respectively. While in the simulated result, we had similar total of arrivals with 1564, 1788.9, 1652.7 arrivals respectively. Also, the accumulated minutes spent in each arc region for the three months was obtained from the simulation and compared to the results from the data. Both statistics came out to be very close as shown in Table XVII.

Table XVII. Simulated Results versus Actual Data Statistics of 2003

Database

Month	Total_Arrivals	EA_OA (mins)	OA_IA (mins)	IA_MA (mins)	MA_RW (mins)
June	1,606	9,435.83	14,772.93	16,221.72	25,666.90
July	1,901	10,852.75	16,581.67	18,281.43	25,614.97
August	1,722	9,817.07	15,032.33	16,601.82	24,160.77

Simulated Data

Month	Total_Arrivals	EA_OA (mins)	OA_IA (mins)	IA_MA (mins)	MA_RW (mins)
June	1,564	9,482.9	14,651	15,923	25,058.42
July	1,788.9	10,537	15,891	17,416	24,174.59
August	1,652.7	9,755.8	14,046.0	16,246.0	23,231.94

We note that from the table that July had the highest total arrivals and the greatest time spent in each arc region except for the MA_RW for both simulated and actual data. The MA_RW arc region saw the greatest time spent by aircrafts for each month indicating heavier traffic encounter in that region. Table XVIII compares the 2004 simulated results to the actual data analysis.

Table XVIII. Simulated Results versus Actual Data Statistics of 2004

Database

Month	Total_Arrivals	EA_OA (mins)	OA_IA (mins)	IA_MA (mins)	MA_RW (mins)
June	1,803	9,570.55	16,128.2	18,136.13	26,380.37
July	2,189	11,323.1	18,348.12	21,186.36	31,976.87
August	2,213	11,559.22	18,609.13	21,683.52	32,304.28

Simulated Data

Month	Total_Arrivals	EA_OA (mins)	OA_IA (mins)	IA_MA (mins)	MA_RW (mins)
June	1,789.9	9,626.3	16,224.0	17,946.0	26,148.24
July	2,173.4	11,285.0	18,299.0	20,997.0	31,793.25
August	2,197.1	11,545	18,566	21,514	32,268.27

From Table XVIII, we see that 2004 had higher number of arrivals than the 2003 total arrivals for June, July, and August. Also, the accumulated time spent between the arcs was greater in 2004 versus in 2003. The difference between the simulated and actual when calculate is not greater than 200 minutes or arrivals for the most part, in both years.

D. Projection of TMA Performance for Year 2005 using Flight Explorer Data

Flight Explorer was used to further analyze TMA to observe if there is any significant improvement even in 2005. Since there was no data available from FAA of 2005 IAH arrival information, the Flight Explorer was the only tool available for us for this projection study. For year 2005, we assumed that the runway constructions and any other miscellaneous obstructions or distractions have all been completed at IAH. We further assumed that by 2005 TMA was fully operational. The results obtained from the flight explorer was compared with those obtained from FAA database in 2004.

1. Set-up of Flight Explorer

In Flight Explorer, three elliptical rings in radius of 200nmi, 100nmi, and 40nmi were created around the IAH airport. The 200nmi and 100nmi rings were used to represent the 'entered area' and 'near destination' times, while the 40nmi ring was used to indicate where the metered arc lies and also to indicate the TRACON boundary. The terminal radar approach control (TRACON) of which there are 184 in the United States, usually provides services to aircrafts that are zero to fifty miles of the airport [2]. However, in developing the rings, observations of the names of the airports that were outside of the 200nmi radius were noted by clicking on the airport overlay button in Flight Explorer and listing them down. The list of airports were added in the Flight Explorer memory so that it would only show and remember the names of the airports that have been selected, rather than showing the names of all airports in the United States. The airports selected in the flight explorer were all regarded as special airports that fall under the name of operational evolution plan (OEP) airports. There are thirty-five of these airports formally known as the OEP-35 airports.

The OEP-35 airports are the thirty-five airports that are considered the most congested airports that needs improvement either in the addition of new runways, increase in air capacity, employment of extra ground or air controllers, or adding extra meter fixes. The decision to select airports from the list of the OEP-35 airports was based on the fact that flights originating from them were more than likely to be experiencing delays when departing because of the congestion at their airports. Therefore, when they finally arrive at the 200nmi ring, they are no longer following their original flight plan due to time factor and allocation, but will depend on the mercy of TMA. So, from the list of the OEP-35 airports, twenty-nine were randomly selected on flight explorer to have flights arriving at IAH. Table XIX shows the twenty-nine OEP-35 airports selected.

Table XIX. Twenty-nine of the OEP-35 Airports

Airport Name	**Code**	**Airport Name**	**Code**
Atlanta	ATL	Miami	MIA
Baltimore/Washington	BWI	Minneapolis St. Paul	MSP
Boston Logan	BOS	Memphis	MEM
Charlotte	CLT	Chicago O'Hare	ORD
Los Angeles	LAX	Dallas / Ft. Worth	DFW
San Diego	SAN	Washington Reagan N	DCA
Detroit Wayne County	DTW	Phoenix	PHX
Tampa	TPA	Philadelphia	PHL
Cincinnati/Covington	CVG	La Guardi	LGA
Seattle	SEA	Washington Dulles	IAD
San Francisco	SFO	Denver	DEN
Ft. Lauderdale	FLL	Las Vegas	LAS
St. Louis	STL	Cleveland	CLE
Orlando	MCO	Salt Lake	SLC
Pittsburg	PIT		

The above twenty-nine airports were selected on the basis that we could have a reasonable amount of flights for our analysis during the short experimentation period.

2. Analysis and Comparison

The period of experimentation for our Flight Explorer analysis was from November 21 through December 31, 2005. During this period of experimenting, three days of the week were picked based on the days that generated the highest number of arrivals in 2004 and 2003 daily arrivals analysis. They are Monday, Thursday, and Friday of each week during November 21 through December 31.

The Flight Explorer log-file data that was generated during this experimentation period saw a total of 6,756 records of flights that entered area, near destination, and arrived. In examining these records, we observed the circulation of some flights either at the entered area or near destination area. Under normal circumstances, we expected to see one entry for entered area, near destination, and arrived of each aircraft. However, in some of the entries for the records, we noticed some aircraft having entered area twice or thrice, and some aircrafts having near destination twice or thrice with different times. Figure 63 shows an example of flight COA1849 having entered area twice.

Date	Time	Condition	Callsign	Dep	Arriv	ETA	STA
11/25/2005	19:47:27	Aircraft arrived	COA1849	FLL	IAH	17:12	19:36
11/25/2005	19:10:09	Aircraft entered area	COA1849	FLL	IAH	17:12	19:36
11/25/2005	19:17:15	Aircraft entered area	COA1849	FLL	IAH	17:12	19:36
11/25/2005	19:28:13	Aircraft near destination	COA1849	FLL	IAH	17:12	19:36

Figure 63. Snap-shot of the original log-file data showing entered area twice

The figure showed an aircraft circulation in the air at the entered area due to a delay occurring at some point below the entered area ring. In a case where we noticed entered area or near destination twice or more, the second time a flight entered area or near destination was discarded so that we can record the actual delay that was experienced by these aircrafts. The other fields that were also discarded in the original log-file data were fields that showed ‘Aircraft In-Flight’, and ‘Aircraft ETA Changed’ under the condition column. As well as some erroneous entries that showed an earlier arrived time but with a later entered area or near destination time. For example, flight USA1234 may show aircraft arrived at 19:20:00 but the near destination or entered area time would read 19:45:36. So, in discarding these entries, the log-file data reduced significantly to 1,432 records. The 1,432 records was what we used to perform our analysis for the rush period 3 time frame for the period November 21 through December 31, 2005.

Table XX shows the time spent between "entered area" to near destination (EA_ND) and near destination to runway (ND_RW) were observed. The EA_ND represents ea_oa to oa_ia arcs while ND_RW represents ia_ma to ma_rw arcs. The analysis of flight explorer indicates the time spent at EA_ND and ND_RW to be 14.175mins and 13.159mins respectively for 2005. These times spent between the arcs in the flight explorer were compared to the times spent in 2003 and 2004.

Table XX. Comparison of time spent between arcs in flight explorer versus 2003 and 2004.

	EA_ND		**EA_ND (ea_oa_ia)**
	2003 Ave Mins	**2004 Ave Mins**	**2005 Nov/Dec**
Jun	15.05	14.736	**14.175 mins**
Jul	14.449	13.978	
Aug	14.479	14.256	

	ND_RW		**ND_RW (ia_ma_rw)**
	2003 Ave Mins	**2004 Ave Mins**	**2005 Nov/Dec**
Jun	25.755	23.643	**13.159 mins**
Jul	22.67	23.521	
Aug	23.46	24.256	

The EA_ND average time for 2005 shows that it was within the range or similar to the times spent between the arcs for the respective months of 2003 and 2004. However, the ND_RW average time saw a significant reduction for the 2005 flight explorer analysis, which is an indication of the full impact of TMA in en route domain to runway. In general, the 2005 flight explorer analysis showed a marked improvement of TMA by reducing delays occurring close to the airport.

When summing the EA_ND and ND_RW times in order to have an idea of the total time spent from the 200nmi ring to runway, we saw that the time spent from EA_RW in 2005 is the shortest among all candidates at 27.334 mins. This time reduction represents on average a -11.2mins, -10.2mins, and -11.1mins against August, July, and June of 2004 respectively. Figure 64 shows the differences in times spent from EA_RW for 2003 and 2004 versus Nov/Dec 2005.

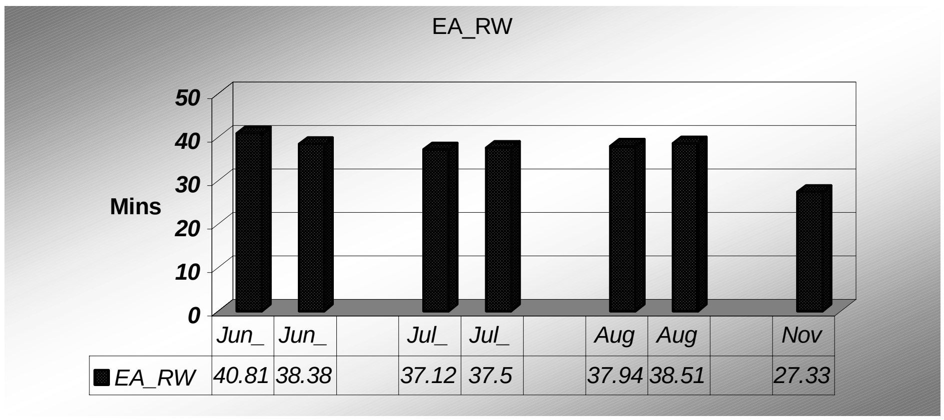


Figure 64. Plot of the time spent from EA_RW for 2003 and 2004 versus 2005

VI. CONCLUSIONS

The operational evaluation of the Traffic Management Advisor was based on the application of both the conventional and proposed metrics. Unlike the conventional metrics, the proposed metric helped to determine distortion in flight arrivals which assists to plan airport activities such as staffing, distribution of traffic load, and changing airport acceptance rate based on pending future rush period. Also, the proposed metric was able to attribute an appreciable quality of service (QoS) level to flight arrivals during peak arrival periods. In general, the operational benefit of the Traffic Management Advisor at IAH was not so predominant; for instance, although TMA improved runway balancing and airport arrival throughput, on-time arrival of flights was neither predictable nor guarantied.

The model and simulation proposed in this research work would assist air traffic controllers and traffic management coordinators to predict future flight arrivals and it also provide an alternative means of economically performing contingency analysis on airport arrival operations.

Future research work: Integrating the arrival control system with the en route control system would establish a common link between them which would provide proper management and scheduling of arrival aircrafts to runways. Also, future work should entail the developing of a simulation model which would minimize fuel cost and assist in stochastic prediction of airline jet fuel expenditure during peak period.

From the en-route analysis, it was observed that 2004 had more arrivals and less delay time experienced at the arc regions. For 2005, supported by Flight Explorer, this analysis showed a drastic improvement of TMA especially at the inner arc to meter arc and meter arc to runway.

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